NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3853

COMPRESSIVE STRESS-STRAIN PROPERTIES OF 2024-T3 ALUMINUM-ALLOY SHEET AT ELEVATED TEMPERATURES

By Eldon E. Mathauser

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
November 1956

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3853

COMPRESSIVE STRESS-STRAIN PROPERTIES OF 2024-T3 ALUMINUM-ALLOY SHEET AT ELEVATED TEMPERATURES

By Eldon E. Mathauser

SUMMARY

Compressive stress-strain test results for 2024-T3 aluminum-alloy sheet are presented for temperatures ranging from room temperature to 700° F and for exposure times from 0.1 to 100 hours. All specimens were loaded parallel to the rolling direction of the sheet and tested at a nominal strain rate of 0.002 per minute. Stress-strain curves are presented for each temperature and exposure time investigated, and significant design data obtained from the curves (compressive yield stress, Young's modulus, secant and tangent moduli, and two stresses useful for determining the maximum compressive strength of plates) are presented in graphical and tabular form. A rate-process relationship is used to determine the exposure time that produces a maximum compressive yield stress for a given temperature and a time-temperature parameter derived from rate-process theory is used to present the compressive yield stresses as a single master curve.

INTRODUCTION

Many studies have been made to determine the effects of elevated temperature and exposure time on the compressive stress-strain properties of aluminum-alloy sheet. (See, for example, refs. 1 to 3.) Although these experimental studies covered a wide range of temperatures and exposure times, no data were obtained which indicate the effects of short exposure times (less than 1/2 hour) on the elevated-temperature compressive properties of these alloys. In addition, for longer exposure times, compressive stress-strain properties were obtained only for temperature increments of about 100° F. The present study was made to determine the effects of short exposure time on the compressive stress-strain properties of aluminum-alloy sheet and also to obtain conventional compressive stress-strain curves for longer exposure times (up to 100 hours) at small temperature increments.

In the present investigation, compressive stress-strain curves were obtained from 2024-T3 aluminum-alloy sheet for exposure times from 0.1 to 100 hours and for temperatures from room temperature to 700° F. A similar study was made on 7075-T6 aluminum-alloy sheet. (See ref. 4.) The stress-strain curves are presented for each temperature and exposure time investigated and significant design data obtained from the curves are given in graphical and tabular form. A study was made to determine whether the exposure time that produces a maximum compressive yield stress at a given temperature can be predicted with the use of a rate-process relationship and to determine whether the compressive yield stresses for various combinations of temperature and exposure time can be plotted as a single curve against a time-temperature parameter derived from rate-process theory.

SYMBOLS

ϵ	strain
σ	stress, psi
σ_{cy}	0.2-percent-offset compressive yield stress, psi
σ_2	stress at which $E_t = \frac{1}{2} E_s$, psi
σ_3	stress at which $E_t = \frac{1}{3} E_s$, psi
E	Young's modulus, psi
E_s	secant modulus, psi
E_t	tangent modulus, psi
t	exposure time, hr
T	temperature, °F
T_R	temperature, °R

TEST SPECIMENS AND PROCEDURES

The compressive stress-strain specimens were 1.00 inch wide and 2.52 inches long. All specimens were machined from one sheet of

2024-T3 aluminum alloy of 0.064-inch nominal thickness with the longitudinal axes of the specimens parallel with the rolling direction of the sheet. The specimens were tested in the compressive stress-strain equipment shown in figure 1 and described in reference 5. Temperature variation over the 1-inch gage length of the specimens did not exceed 5° during the tests, and specimen temperatures during the tests were maintained within ±5° F of the nominal test temperature. The rate of loading was controlled to achieve as closely as possible a strain rate of 0.002 per minute for all specimens.

For exposure times of 1 hour or less, the specimens were inserted in the preheated compressive stress-strain test fixtures and were maintained at test temperature for the desired time prior to loading. Exposure time for these specimens is defined as the time at test temperature prior to loading plus the time required to load the specimens to the compressive yield stress. For exposure times greater than 1 hour, the specimens were heated in an oven at the desired test temperatures for the designated exposure times. These specimens were then cooled to room temperature and subsequently reheated to the test temperatures in the compression stress-strain equipment prior to loading. Testing of these specimens began immediately after the desired test temperature was achieved.

Three specimens were tested at each temperature for a 0.5-hour exposure. Only one specimen was tested at each of the other temperatures and exposure times.

RESULTS AND DISCUSSION

Test Results

Compressive stress-strain curves obtained from the tests for temperatures up to 700° F and for a 0.5-hour exposure at the elevated temperatures are given in figure 2. The curves are typical results obtained from tests of three specimens at each temperature. The 0.2-percent-offset compressive yield stresses are indicated by the tick marks. Figures 3 to 15 present compressive stress-strain curves obtained for test temperature from 200° F to 700° F and for exposure times from 0.1 to 100 hours. A summary of the compressive properties obtained from the stress-strain curves shown in figures 2 to 15 is given in table I.

A curve of average values of Young's modulus obtained from the tests at each temperature is given in figure 16. The scatter in the experimental values of Young's modulus ranged from approximately ±2 percent at the low test temperatures to ±5 percent at the high test temperatures. No significant change in Young's modulus was obtained at a given temperature for different exposure times. Results of studies by previous investigators have indicated that no significant change in Young's modulus should be expected for different exposure times at a given temperature. (For example, see ref. 3.)

The effect of exposure time at the different test temperatures on the compressive yield stress is shown in figure 17. Experimental results are shown by the symbols. Solid lines are drawn through the data within the range of exposure times investigated at each temperature. The dashed curves indicate estimated values of compressive yield stresses obtained from a cross plot of the data in figure 17 into the form shown in figure 18. Exposure times ranging from 0.1 to 100 hours appear to have no significant effect on the compressive yield stress for temperatures up to 250° F. At 300° F artificial aging produces an increase in the compressive yield stress for exposure times greater than 10 hours. From 350° F to 425° F the compressive yield stress is increased to a maximum value by artificial aging for different exposure times at each temperature; however, additional exposure produces overaging with a resultant decrease in strength. Above 425° F the compressive yield stress was maximum for the shortest exposure time at each test temperature and decreased continually with increasing exposure time. The increase in compressive strength obtained with the 2024-T3 aluminum-alloy sheet at various temperatures is anticipated because this material in the "as received" condition is naturally aged. Artificial aging resulting from exposure at elevated temperatures produces an increase in strength. In contrast, the compressive strength of 7075-T6 aluminum-alloy sheet is not increased by exposure at elevated temperatures because this material in the "as received" condition is artificially aged to maximum strength. (See ref. 4.)

Figure 19 presents the change of secant modulus with stress for temperatures ranging from room temperature to 700° F for a 0.5-hour exposure at the elevated temperatures. Figures 20 to 32 show the change of secant modulus with stress at each test temperature for different exposure times. The change of tangent modulus with stress at the elevated temperatures is given in figure 33 for the 0.5-hour exposure and in figures 34 to 46 for all other exposure times investigated at the elevated temperatures. The secant and tangent moduli presented here were determined from stress-strain curves obtained for a given strain rate. Considerably different values of tangent moduli may be expected for other strain rates; however, the values of secant modulus are not expected to change appreciably.

Figures 47 and 48 present the changes of σ_2 and σ_3, respectively, with exposure time for the different test temperatures. The stresses σ_2 and σ_3 as defined in reference 6 are the stresses at which $E_t = \frac{1}{2} E_s$ and $E_t = \frac{1}{3} E_s$, respectively. These stresses were shown to be useful in the determination of maximum compressive strength of plates (ref. 6) and may also be considered to be suitable definitions of the compressive strength of materials at elevated temperatures. Both σ_2 and σ_3 show changes with exposure time at the different test temperatures that approximate the changes in the compressive yield stress. The compressive yield stress, however, is greater than either σ_2 or σ_3 at any corresponding temperature and exposure time. The values of σ_2 and σ_3 determined from each stress-strain curve are listed in table I.

Prediction of Time-Temperature Combinations That Produce Maximum Yield Stress

The following rate-process relationship was investigated to determine whether time-temperature combinations which produce maximum compressive yield stresses can be predicted satisfactorily:

$$t_1 e^{-\Delta H/RT_1} = t_2 e^{-\Delta H/RT_2} \tag{1}$$

where

t_1, t_2 exposure time, hr

T_1, T_2 temperature, $^{\circ}R$

R universal gas constant, $1.10 \frac{\text{cal}}{\text{mol-}^{\circ}\text{R}}$

ΔH activation energy for aluminum alloys, $36 \times 10^3 \frac{\text{cal}}{\text{mol}}$ (ref. 7)

Experimental data given in the literature (for example, fig. 8 of ref. 8) indicate that maximum compressive yield stress for 2024-T3 aluminum-alloy sheet is obtained for $T_1 = 400^{\circ}$ F and $t_1 = 1\frac{1}{2}$ hours. This time-temperature combination was substituted into equation (1) to determine other time-temperature combinations that were expected to give maximum compressive yield stress. The predicted time-temperature combinations are shown by the curve in figure 49. Experimental results obtained from the curves of figure 17 are shown by the symbols in figure 49. The predicted results are in good agreement with the experimental data. Equation (1) thus appears to be satisfactory for estimating time-temperature combinations that give maximum values of compressive yield stress. In addition, tensile-yield-stress data for 2024-T3 aluminum-alloy sheet (refs. 9 and 10) indicate that equation (1) will also predict time-temperature combinations which produce maximum tensile yield stresses.

Master Compressive-Yield-Stress Curve

A time-temperature parameter used previously for correlating the hardness of steels with time and tempering temperatures (ref. 11) was investigated to determine whether the yield stresses shown in figure 17 could be presented as a single master curve. The time-temperature parameter is $T_R(28 + \log_{10} t)$, where T_R is temperature in degrees Rankine, 28 is a material constant (determined from equation [A8] of ref. 11), and t is exposure time in hours. Compressive yield stresses obtained in the present investigation are plotted as a function of the time-temperature parameter in figure 50. Test results are shown for temperatures from 300° F to 700° F and for exposure times from 0.1 to 100 hours. Compressive yield stresses for temperatures below 300° F are omitted from this figure. For these relatively low test temperatures no significant changes in yield stresses were obtained in the range of exposure times investigated. The experimental compressive yield stresses that are joined by the dashed lines in figure 50 were obtained for time-temperature combinations which do not produce either maximum compressive yield stress or overaging of the material. Such time-temperature combinations all lie in the region below the curve in figure 49. The experimental compressive yield stresses which lie on the master curve (solid line) of figure 50 were obtained for time-temperature combinations that lie on the curve of figure 49 or in the region above this curve. The master curve of figure 50 appears useful for estimating compressive yield stresses for 2024-T3 aluminum-alloy (within the time-temperature range investigated) with the following limitations: Only those time-temperature combinations that correspond to maximum strength or overaging of the material (fig. 49) may be considered. No data are available at present to indicate whether the master curve can be used successfully to predict compressive yield stresses outside of the time-temperature range investigated, particularly for very short exposure times at high temperatures.

CONCLUDING REMARKS

The results of compressive stress-strain tests of 2024-T3 aluminum-alloy sheet indicate that exposure times ranging from 0.1 to 100 hours produce no significant change in compressive yield stress for temperatures up to 250° F. At 300° F the compressive yield stress is not changed appreciably until after an exposure of 10 hours. For temperatures from 350° F to 425° F the compressive yield stress increases as a result of artificial aging to a maximum value at different exposure times which depend on the temperature. Exposure times which give maximum values of compressive yield stress in this temperature range are predicted by a rate-process relationship and are in good agreement with the experimental results. From 425° F to 700° F the compressive yield stress for each test temperature is maximum at the shortest exposure time of 0.1 hour and decreases continually with increasing exposure time. The test results show no significant variation in Young's modulus due to exposure time at any given test temperature. The compressive yield stresses obtained for time-temperature combinations which produce either maximum yield stress or overaging of the material are plotted in terms of a time-temperature parameter to obtain a master yield-stress curve.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 9, 1956.

REFERENCES

1. Roberts, William M., and Heimerl, George J.: Elevated-Temperature Compressive Stress-Strain Data for 24S-T3 Aluminum-Alloy Sheet and Comparisons With Extruded 75S-T6 Aluminum Alloy. NACA TN 1837, 1949.

2. Doerr, Dale D.: Compressive, Bearing, and Shear Properties of Several Non-Ferrous Structural Sheet Materials (Aluminum and Magnesium Alloys and Titanium) at Elevated Temperatures. Proc. A.S.T.M., vol. 52, 1952, pp. 1054-1078.

3. Flanigan, Alan E., Tedsen, Leslie F., and Dorn, John E.: Compressive Properties of Aluminum-Alloy Sheet at Elevated Temperatures. Proc. A.S.T.M., vol. 46, 1946, pp. 951-967.

4. Mathauser, Eldon E.: Compressive Stress-Strain Properties of 7075-T6 Aluminum-Alloy Sheet at Elevated Temperatures. NACA TN 3854, 1956.

5. Hughes, Philip J., Inge, John E., and Prosser, Stanley B.: Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures. NACA TN 3315, 1954.

6. Anderson, Roger A., and Anderson, Melvin S.: Correlation of Crippling Strength of Plate Structures With Material Properties. NACA TN 3600, 1956.

7. Sherby, Oleg D., Orr, Raymond L., and Dorn, John E.: Creep Correlations of Metals at Elevated Temperatures. Twenty-fifth Tech Rep. (Ser. 22, Issue 25, N7-onr-295, Task Order II, NR-031-048), Univ. Calif. Inst. Eng. Res., Mar. 1, 1953.

8. Mathauser, Eldon E., and Deveikis, William D.: Investigation of the Compressive Strength and Creep Lifetime of 2024-T3 Aluminum-Alloy Plates at Elevated Temperatures. NACA TN 3552, 1956. (Supersedes NACA RM L55E11b.)

9. Dix, E. H., Jr.: New Developments in High Strength Aluminum Alloy Products. Trans. A.S.M., vol. 35, 1945, pp. 130-148.

10. Kotanchik, Joseph N., Woods, Walter, and Zender, George W.: The Effect of Artificial Aging on the Tensile Properties of Alclad 24S-T and 24S-T Aluminum Alloy. NACA WR L-257, 1943 (Formerly NACA RB 3H23).

11. Hollomon, J. H., and Jaffe, L. D.: Time-Temperature Relations in Tempering Steel. Trans. Am. Inst. Mining and Metallurgical Eng., vol. 162, 1945, pp. 223-248.

TABLE I

COMPRESSIVE PROPERTIES OF 2024-T3 ALUMINUM-ALLOY SHEET FOR VARIOUS TEMPERATURES AND EXPOSURE TIMES

[Nominal sheet thickness, 0.064 inch; nominal strain rate, 0.002 per minute]

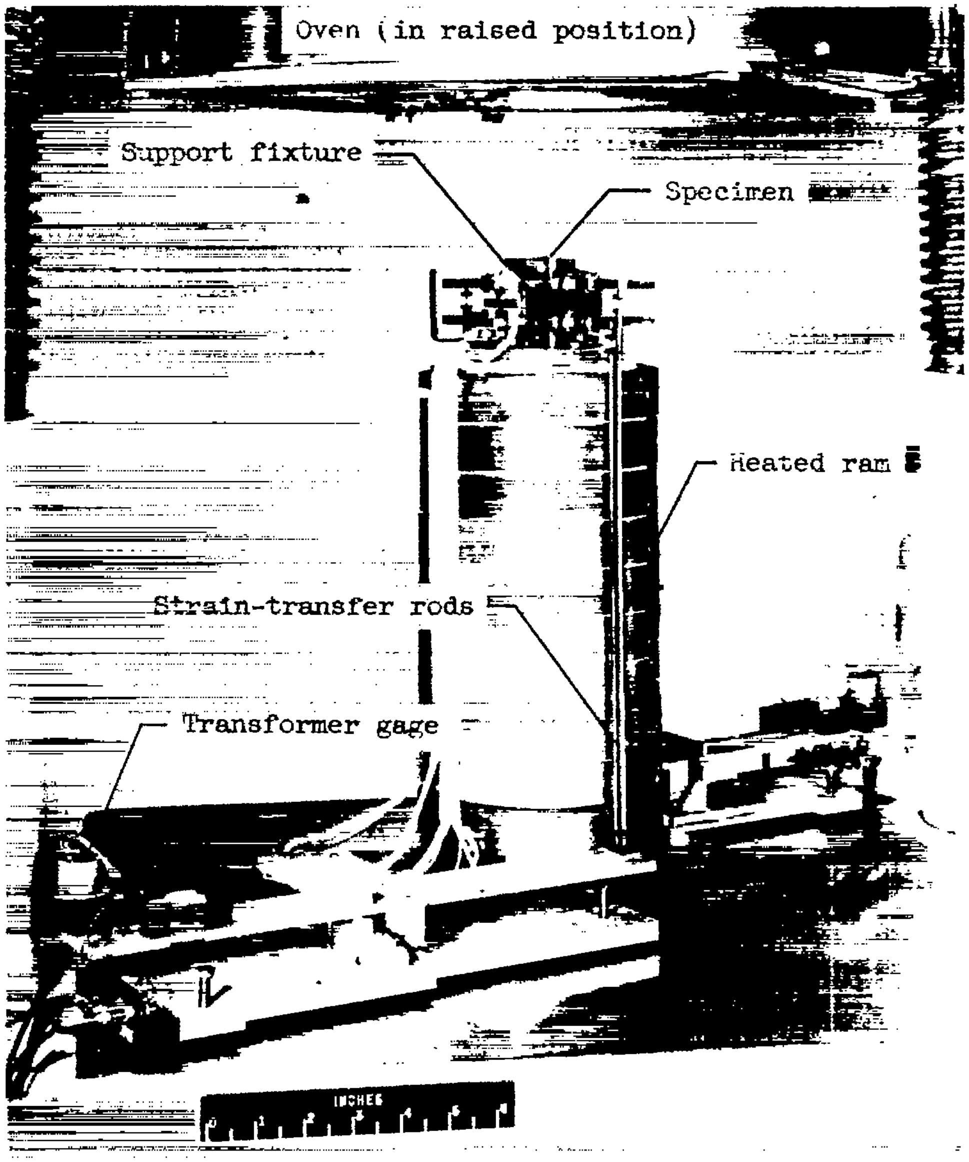
T, °F	Exposure, hr	σ_{cy}, psi	E, psi	σ_2, psi	σ_3, psi
Room	-----	44.0×10^3	10.7×10^6	36.9×10^3	43.3×10^3
200	0.1	44.5	10.3	37.5	43.5
200	.5	43.5	10.5	36.6	42.1
200	1	43.5	10.4	36.6	42.1
200	10	43.4	10.5	36.6	42.1
200	100	43.7	10.3	37.0	42.6
250	.1	44.0	10.2	37.2	42.8
250	.5	43.0	10.1	36.2	42.6
250	1	42.1	10.3	35.6	41.0
250	10	42.5	10.2	35.6	41.0
250	100	43.2	10.4	36.6	42.4
300	.1	40.9	9.9	34.6	39.3
300	.5	41.3	10.0	34.7	39.4
300	1	40.4	10.2	34.3	38.9
300	10	41.9	9.9	35.3	39.8
300	100	50.8	9.8	44.4	48.9
350	.1	38.8	9.6	32.6	37.3
350	.5	38.9	9.6	33.3	38.2
350	1	39.5	9.6	33.5	38.6
350	10	49.4	9.9	43.5	48.0
350	14	54.3	9.8	48.8	51.8
350	18	55.3	9.7	51.8	53.3
350	22	53.0	9.9	49.5	51.1
350	100	50.5	9.7	46.5	48.2
375	.1	37.1	9.4	31.5	35.5
375	.5	39.7	9.5	33.4	37.8
375	1	41.8	9.4	36.0	40.0
375	2	44.6	9.6	39.1	42.6
375	4	49.6	9.6	44.5	47.5
375	6	52.1	9.7	47.6	50.5
375	8	50.6	9.8	45.9	48.8
375	10	49.0	9.5	45.5	47.7
375	100	44.8	9.5	41.2	43.0
400	.1	37.0	9.6	31.3	35.4
400	.2	38.1	9.3	32.7	37.1
400	.3	38.5	9.5	32.7	37.1
400	.4	41.0	9.1	34.9	39.3
400	.5	41.6	9.4	36.9	41.6
400	1	49.8	9.1	45.6	47.3
400	2	50.8	9.4	47.0	48.9
400	3	49.4	9.7	45.6	47.2
400	4	47.2	9.5	43.5	45.3
400	10	42.7	9.6	39.1	41.0
400	100	35.0	9.4	31.5	33.0
425	.1	39.1	9.2	33.6	37.9
425	.2	42.2	9.0	36.6	41.1
425	.3	42.9	9.5	38.0	42.0
425	.4	45.9	9.4	41.1	43.9
425	.5	46.3	9.3	42.0	44.0
425	.6	46.8	9.0	43.1	44.9
425	.7	47.0	9.4	43.5	45.0
425	.8	46.2	9.3	42.2	44.0
425	1	43.7	9.5	39.9	41.6

TABLE I.- Concluded

COMPRESSIVE PROPERTIES OF 2024-T3 ALUMINUM-ALLOY SHEET FOR VARIOUS TEMPERATURES AND EXPOSURE TIMES

[Nominal sheet thickness, 0.064 inch; nominal strain rate, 0.002 per minute]

T, °F	Exposure, hr	σ_{cy}, psi	E, psi	σ_2, psi	σ_3, psi
450	0.1	44.6×10^3	8.9×10^6	39.8×10^3	41.8×10^3
450	.2	43.0	8.8	38.4	41.0
450	.3	41.8	9.3	37.3	39.7
450	.4	40.1	9.2	36.5	38.4
450	.5	39.2	9.1	35.5	37.5
450	1	38.1	9.3	34.4	36.3
450	5	33.5	9.1	30.2	31.9
450	10	32.3	8.8	29.7	31.4
450	50	28.2	9.1	25.5	26.9
450	100	24.5	9.3	21.5	22.6
500	.1	35.9	8.5	32.5	34.2
500	.2	34.1	8.4	30.6	32.7
500	.3	33.9	8.3	30.4	32.4
500	.4	32.6	8.5	29.0	30.9
500	.5	32.1	8.5	28.6	30.4
500	1	30.3	8.7	27.0	28.6
500	5	25.5	8.4	22.6	23.5
500	10	23.5	8.7	20.7	22.0
500	50	20.5	8.8	17.4	18.9
500	100	19.0	8.4	16.0	17.5
550	.1	25.7	7.9	22.8	24.5
550	.2	24.6	8.2	21.5	23.3
550	.3	23.4	7.7	19.8	21.8
550	.4	22.9	7.6	19.5	21.3
550	.5	22.4	8.1	19.0	21.2
550	1	21.3	8.0	18.6	20.1
600	.1	20.3	7.2	17.7	19.2
600	.2	19.0	6.9	16.1	17.8
600	.3	18.2	6.8	15.6	17.0
600	.4	16.8	6.8	14.5	15.6
600	.5	16.7	7.2	14.3	15.6
600	1	15.2	7.1	12.6	13.9
650	.1	12.8	6.6	10.4	11.4
650	.2	12.0	6.1	9.6	10.8
650	.3	11.6	6.4	9.2	10.4
650	.4	10.8	6.3	8.6	9.7
650	.5	10.9	6.3	8.8	10.0
650	1	9.8	6.2	7.9	8.8
700	.1	8.6	5.2	6.5	7.6
700	.2	7.9	5.6	5.9	7.0
700	.3	7.2	5.4	5.3	6.4
700	.4	7.0	5.5	5.3	6.4
700	.5	7.2	5.4	5.3	6.4
700	1	6.4	5.3	4.8	5.5
700	10	5.0	5.8	3.7	4.5
700	100	4.8	5.7	3.5	4.2



L-85457.1

Figure 1.- Equipment for compressive stress-strain tests.

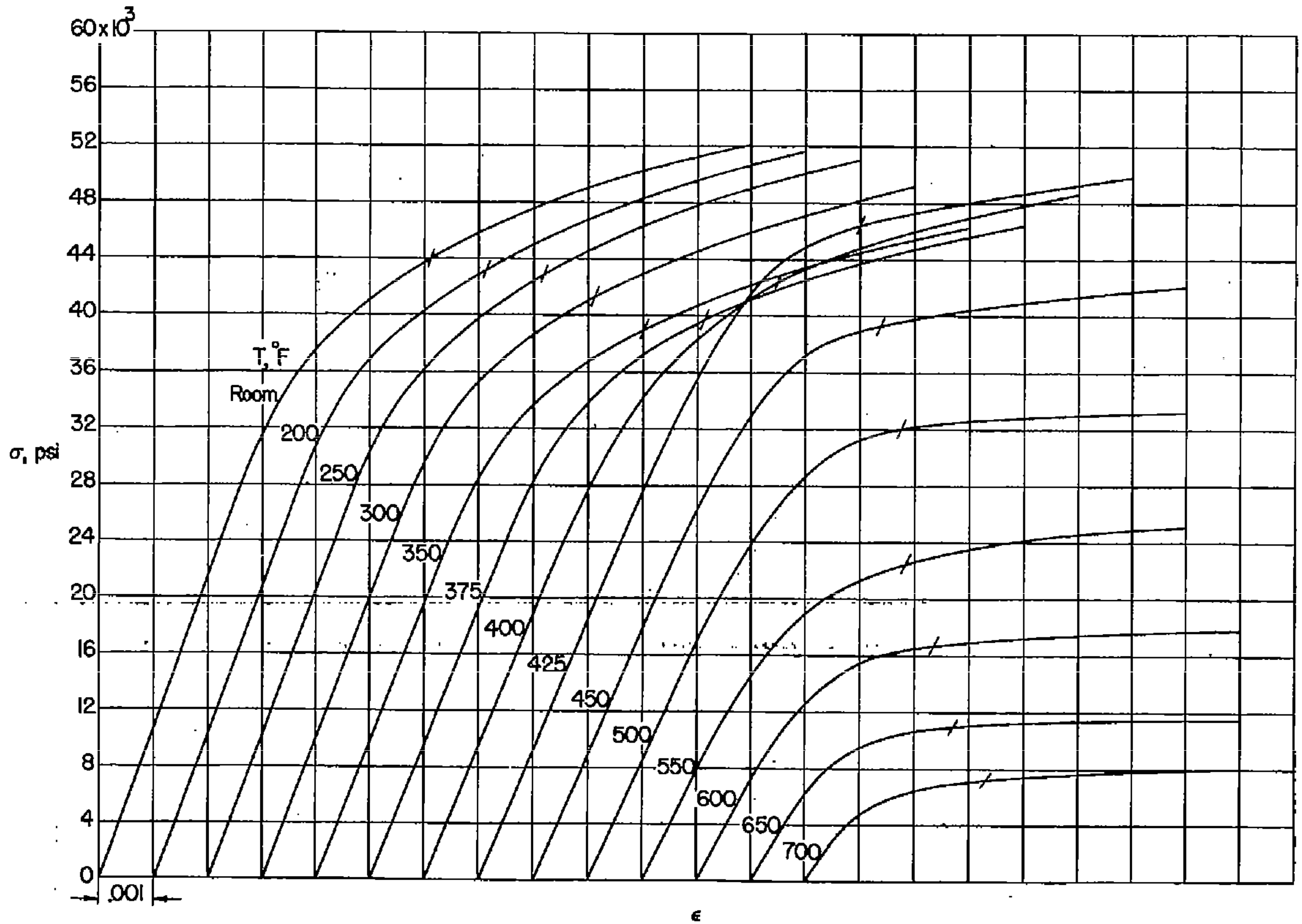


Figure 2.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet. 0.5-hour exposure; strain rate, 0.002 per minute.

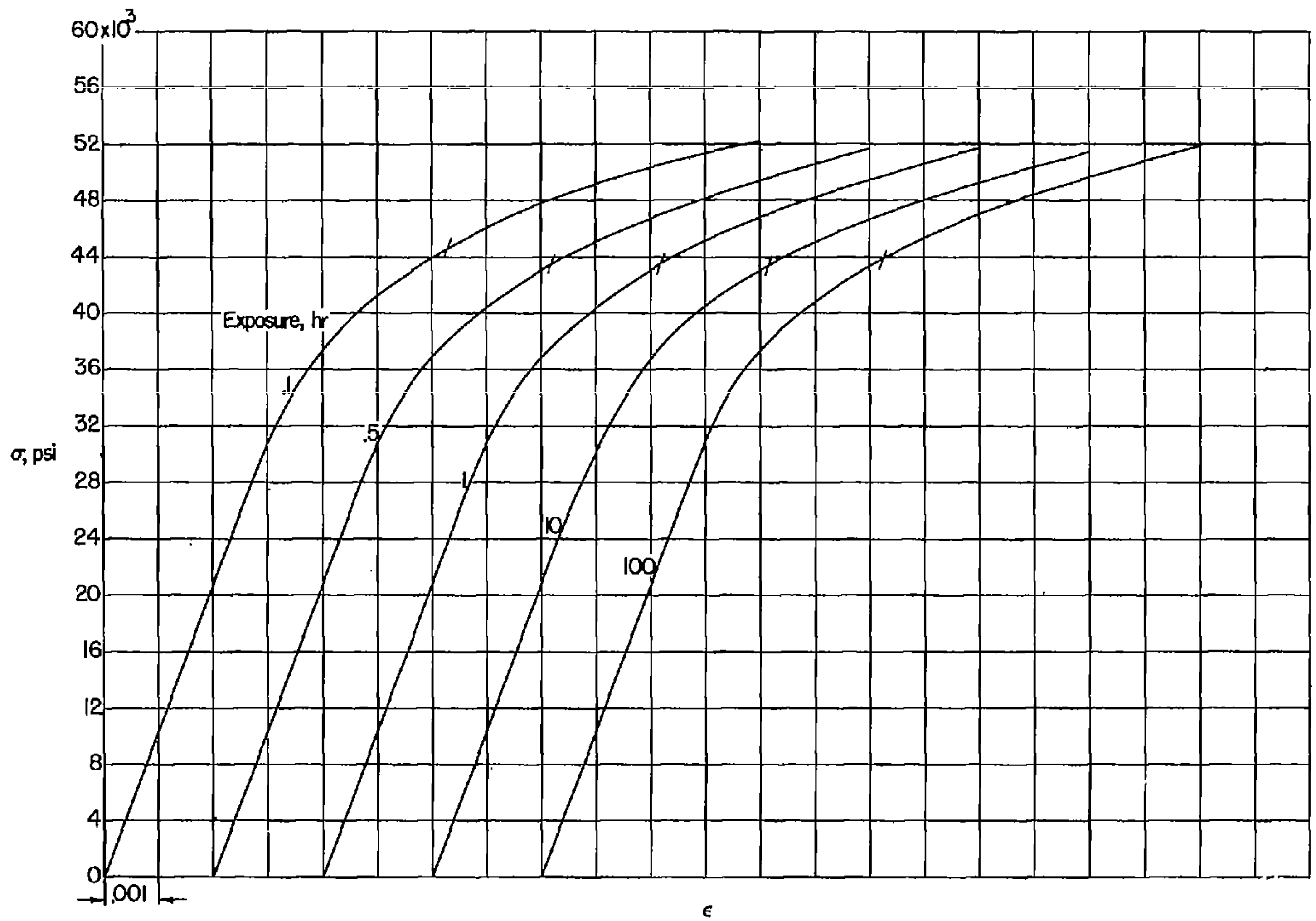


Figure 3.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 200° F.

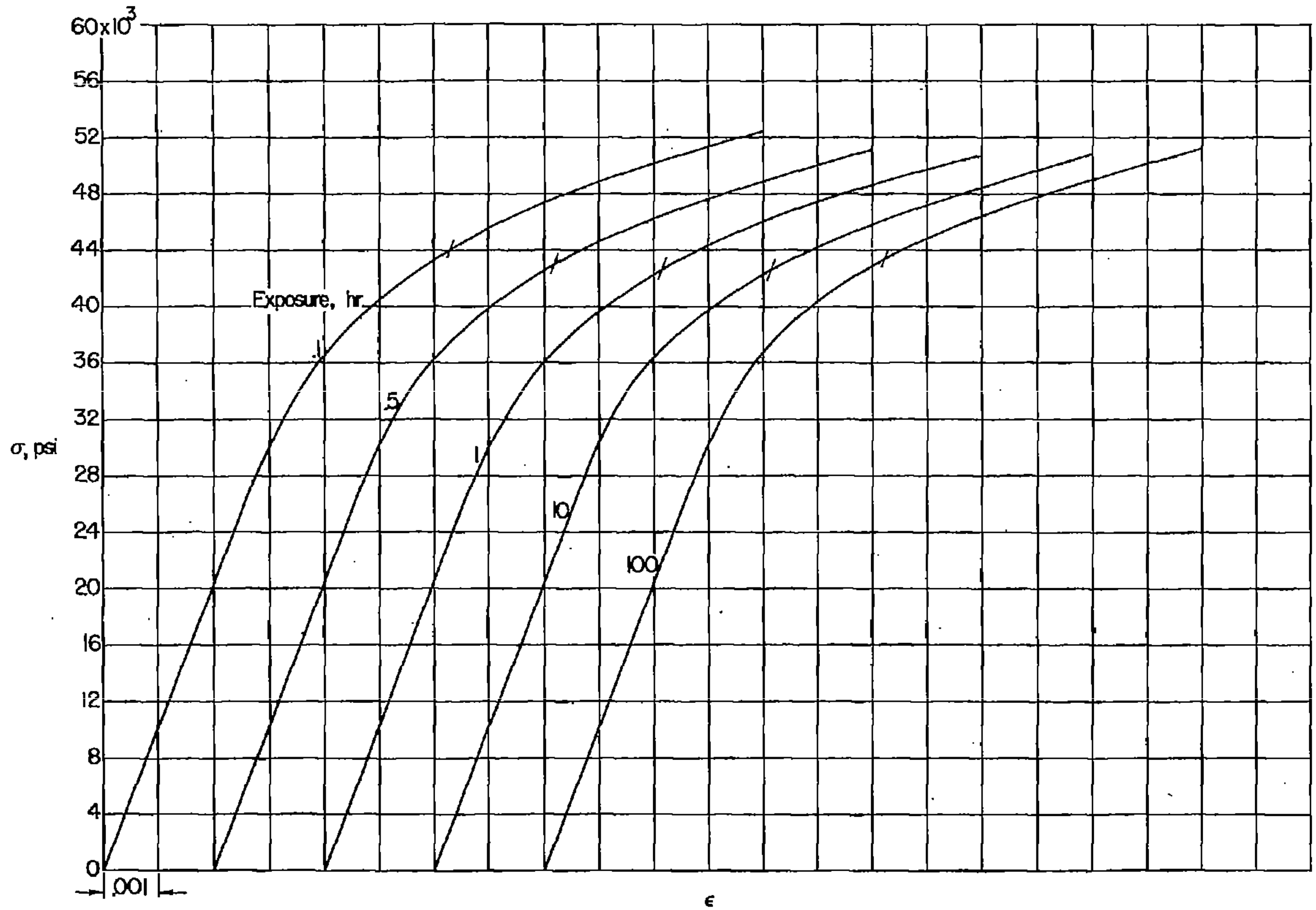


Figure 4.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 250° F.

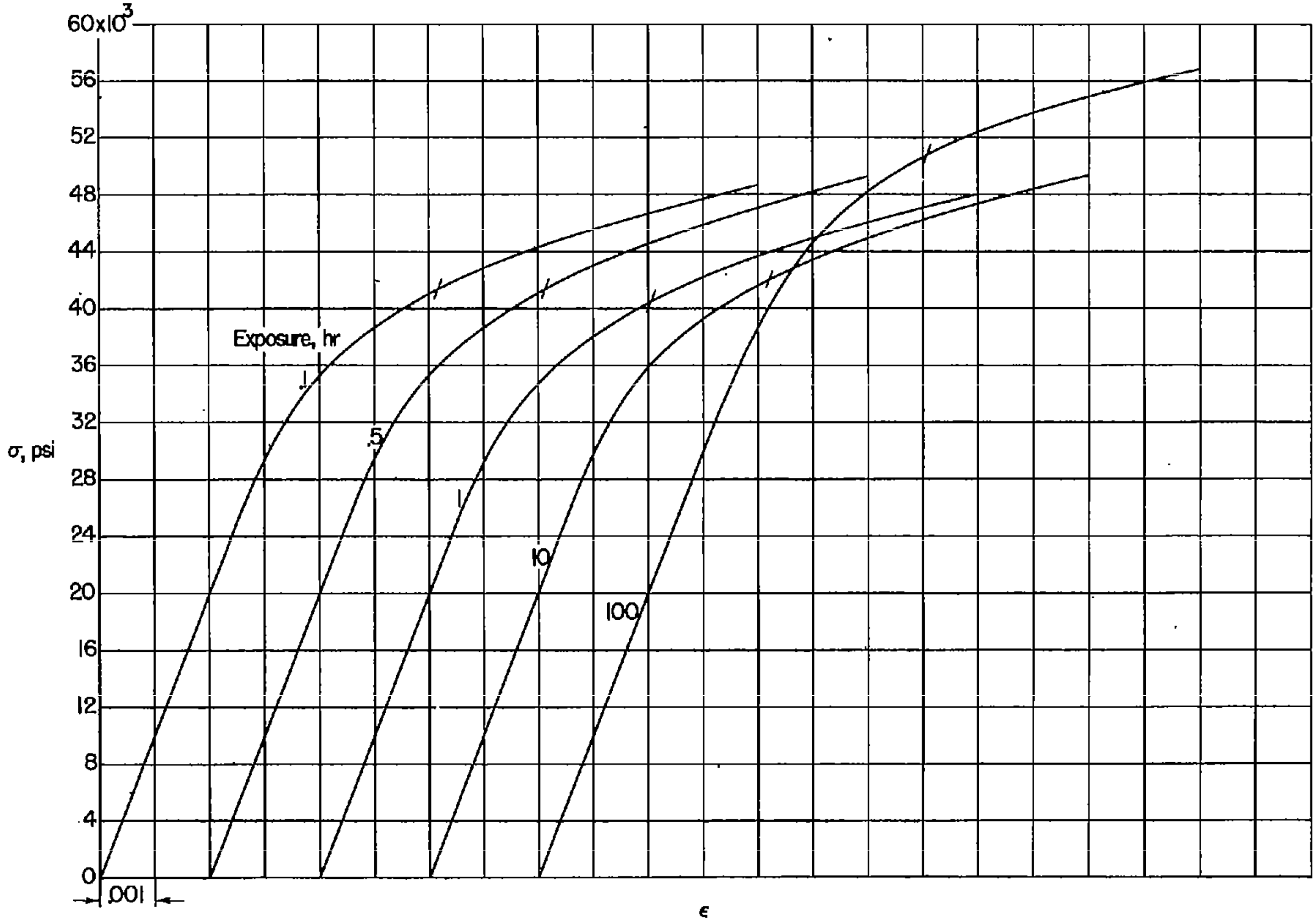


Figure 5.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 300° F.

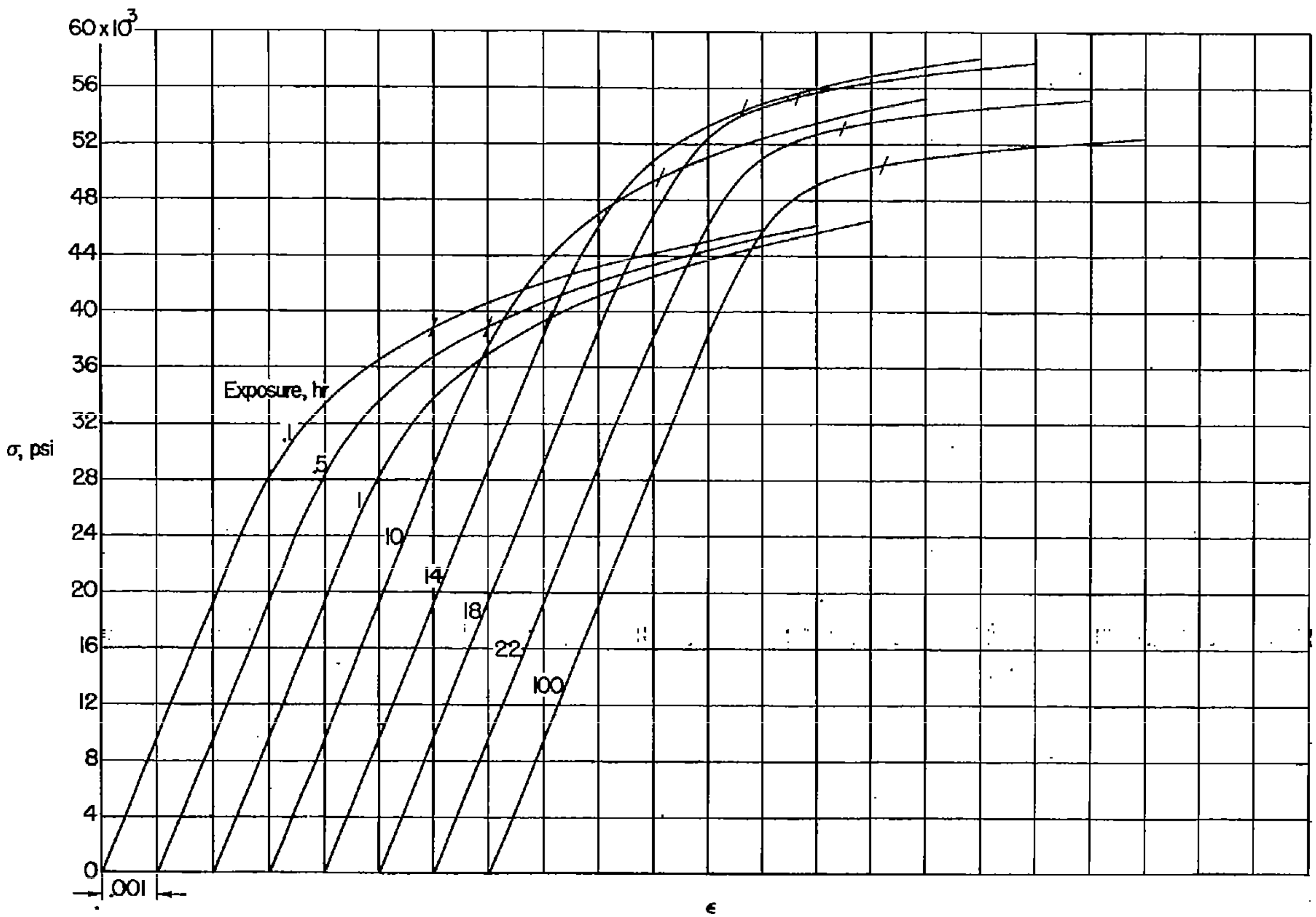


Figure 6.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 350° F.

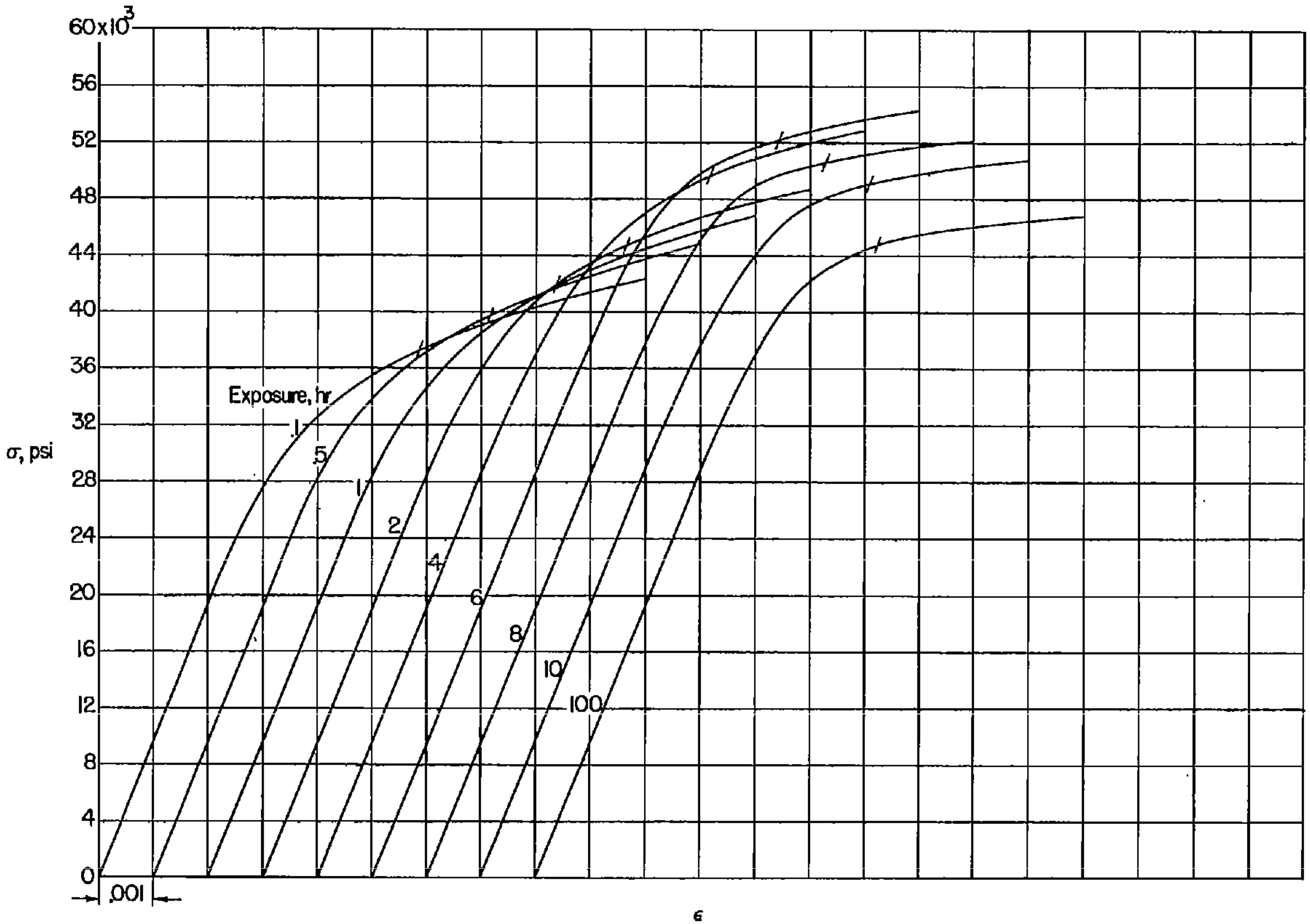


Figure 7.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 375° F.

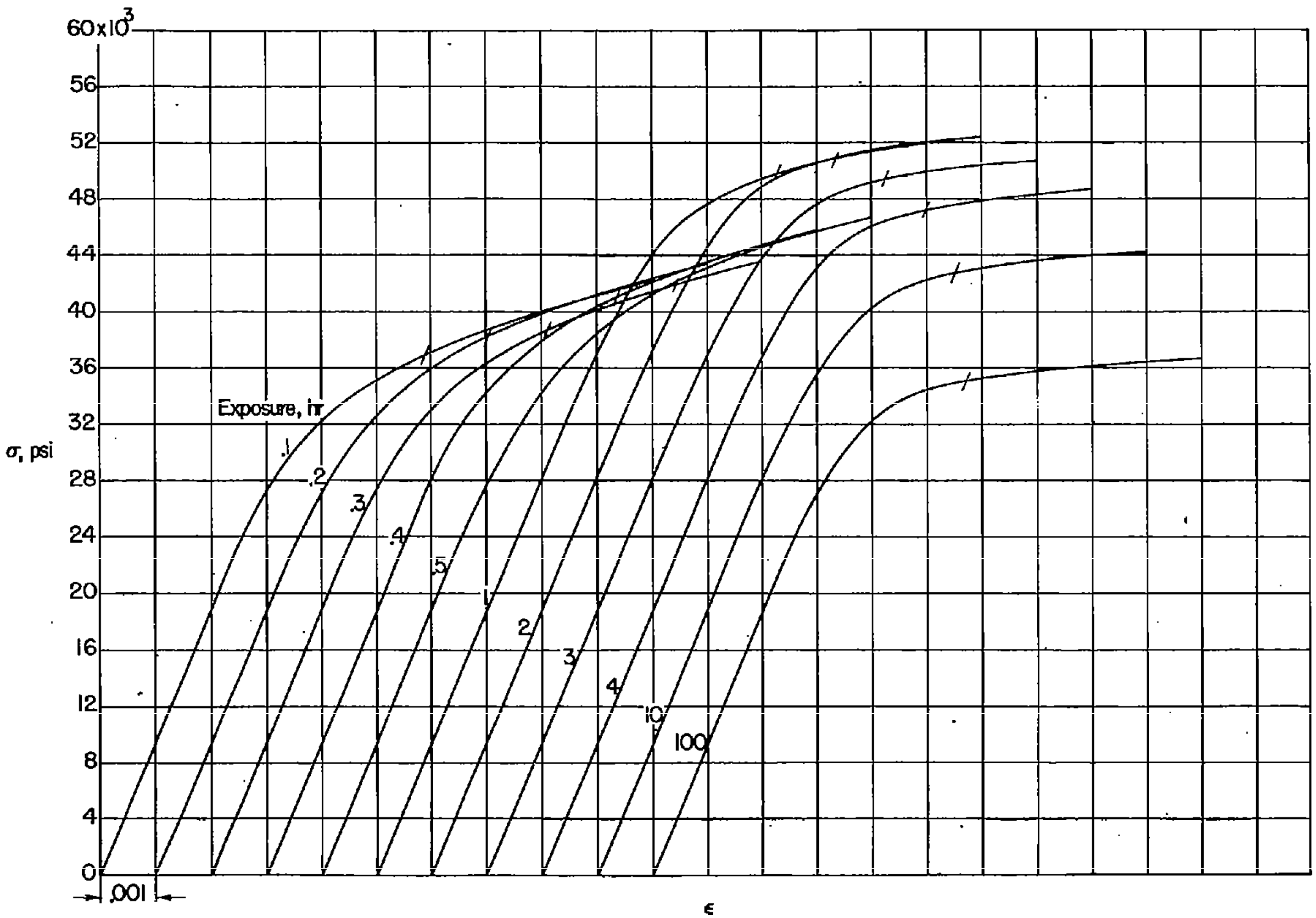


Figure 8.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 400° F.

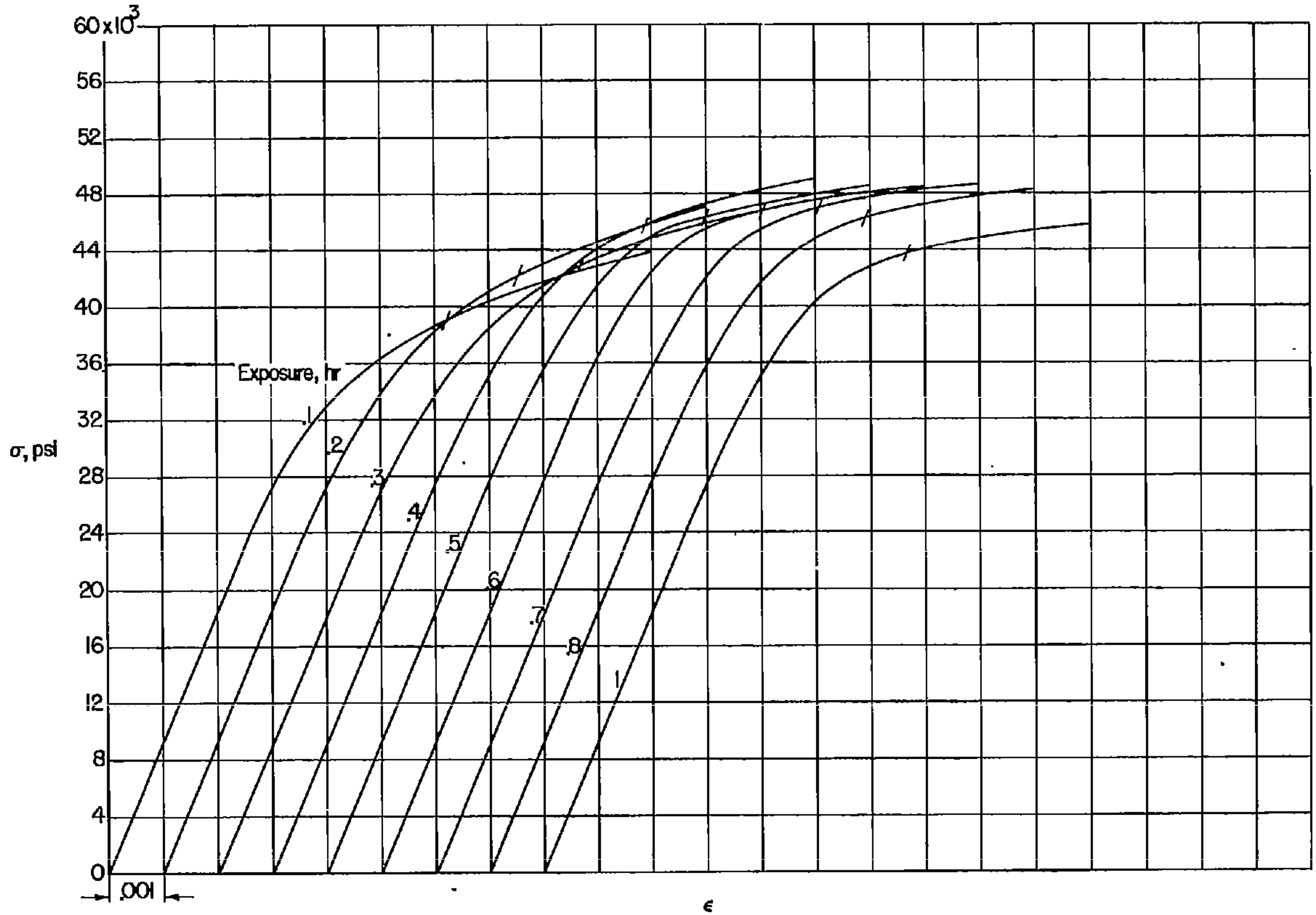


Figure 9.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 425° F.

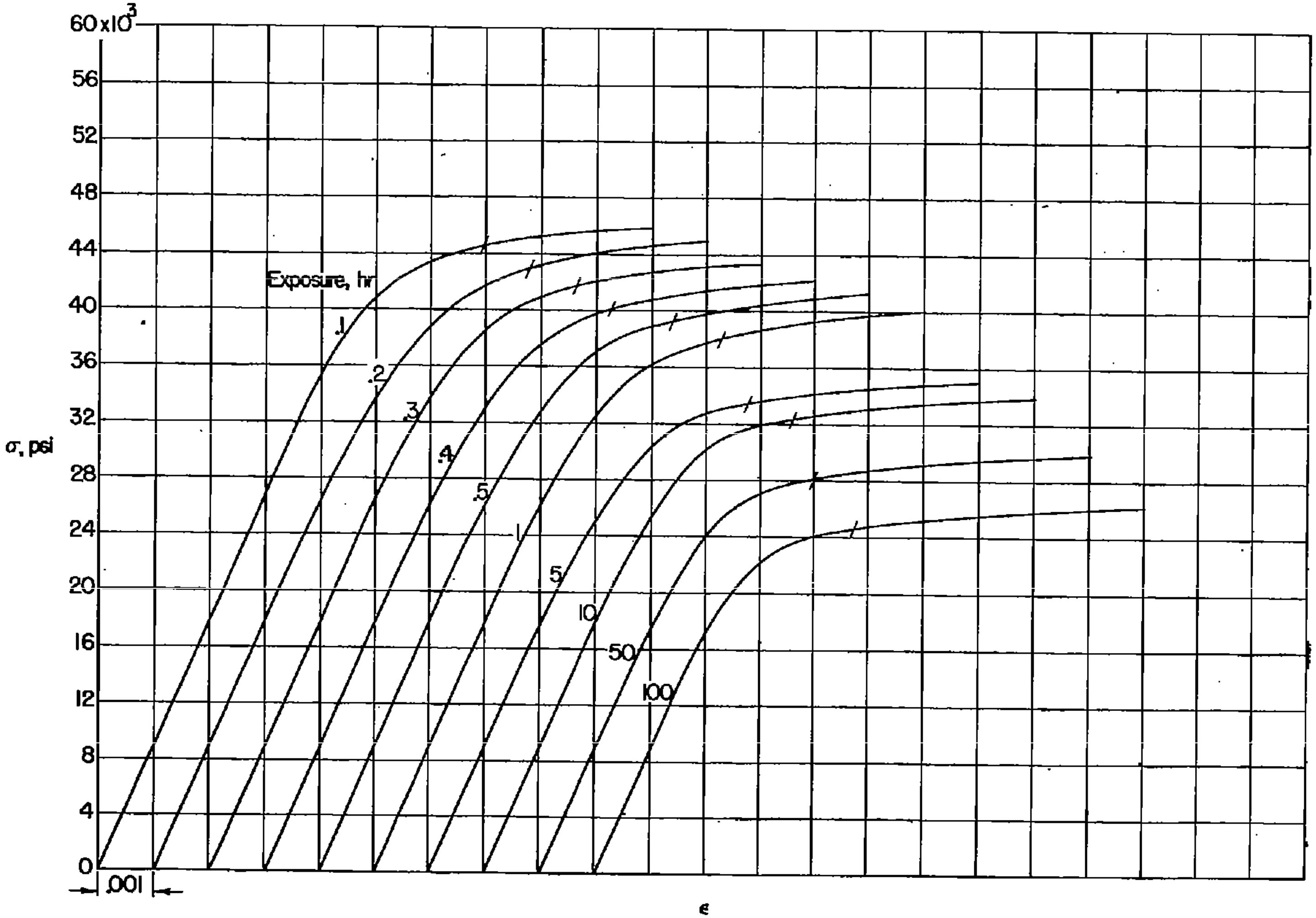


Figure 10.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 450° F.

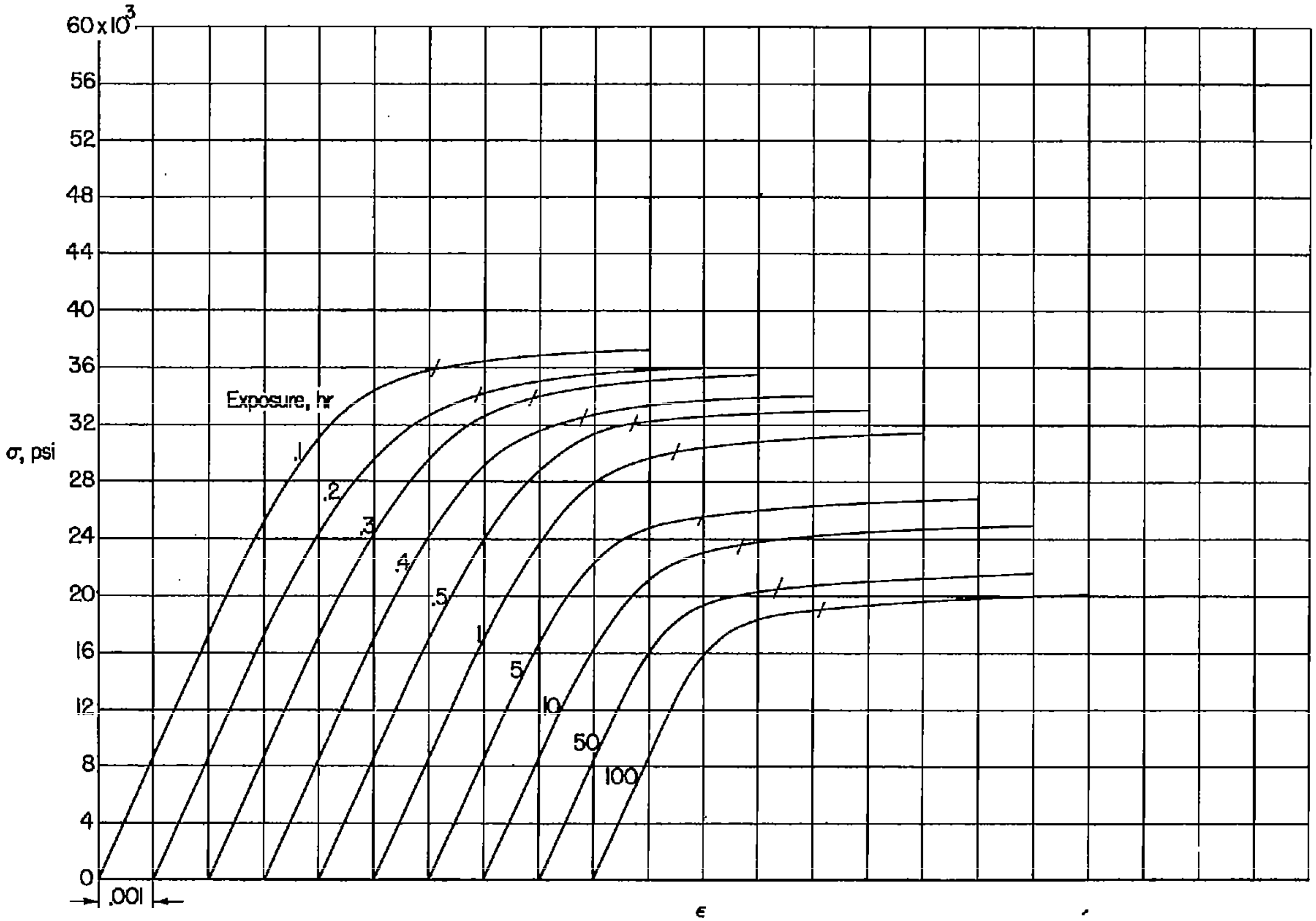


Figure 11.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 500° F.

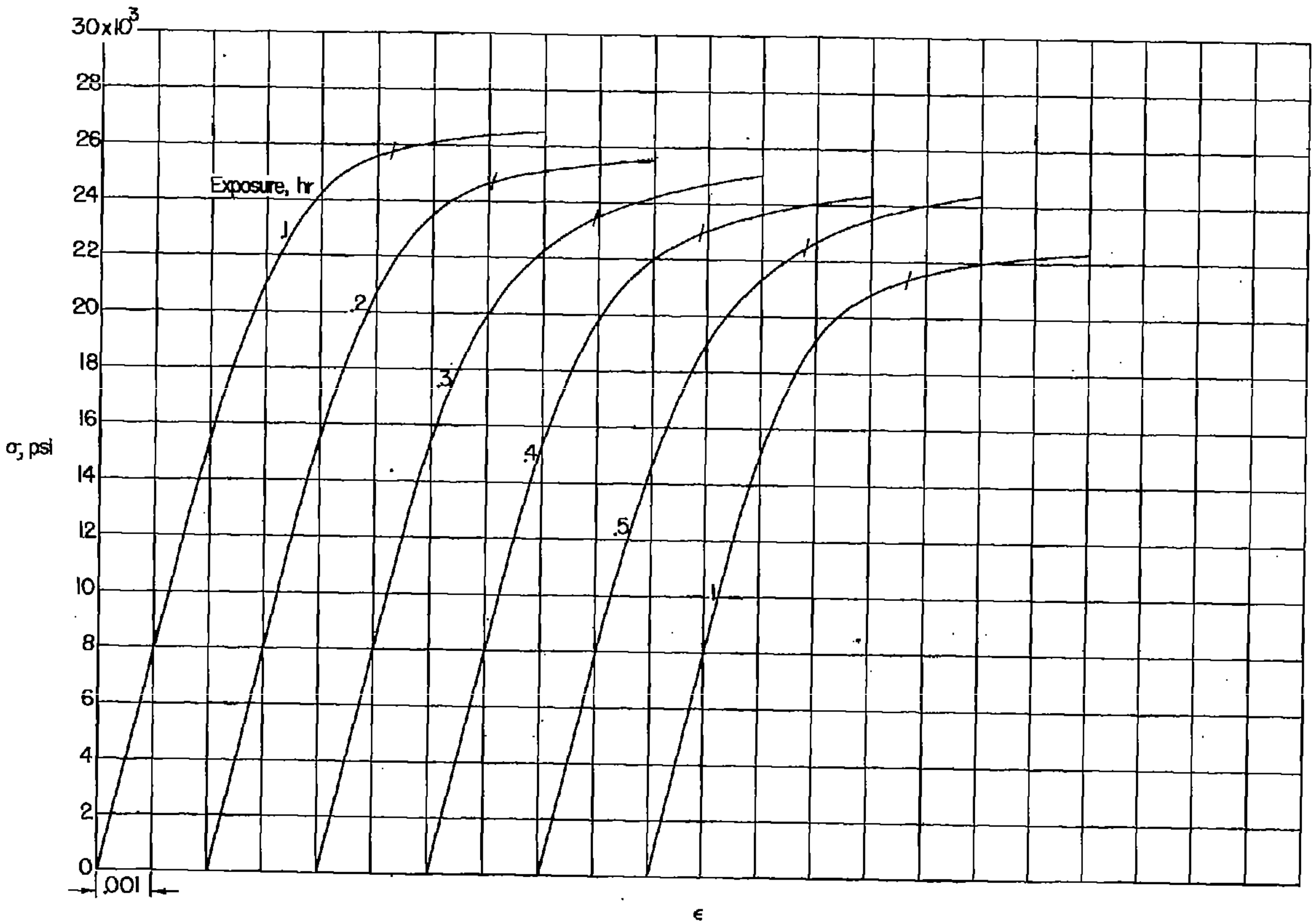


Figure 12.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 550° F.

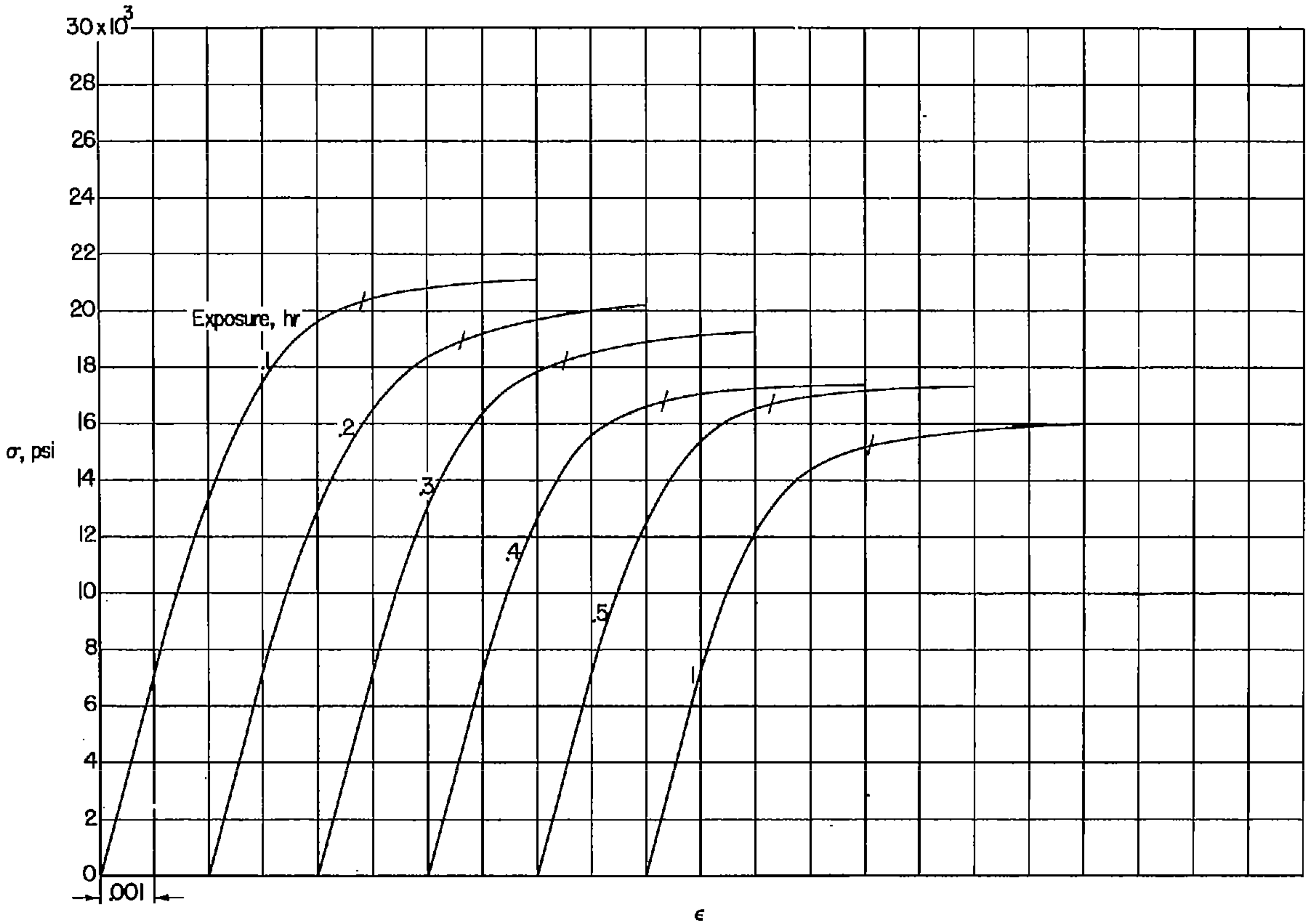


Figure 13.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 600° F.

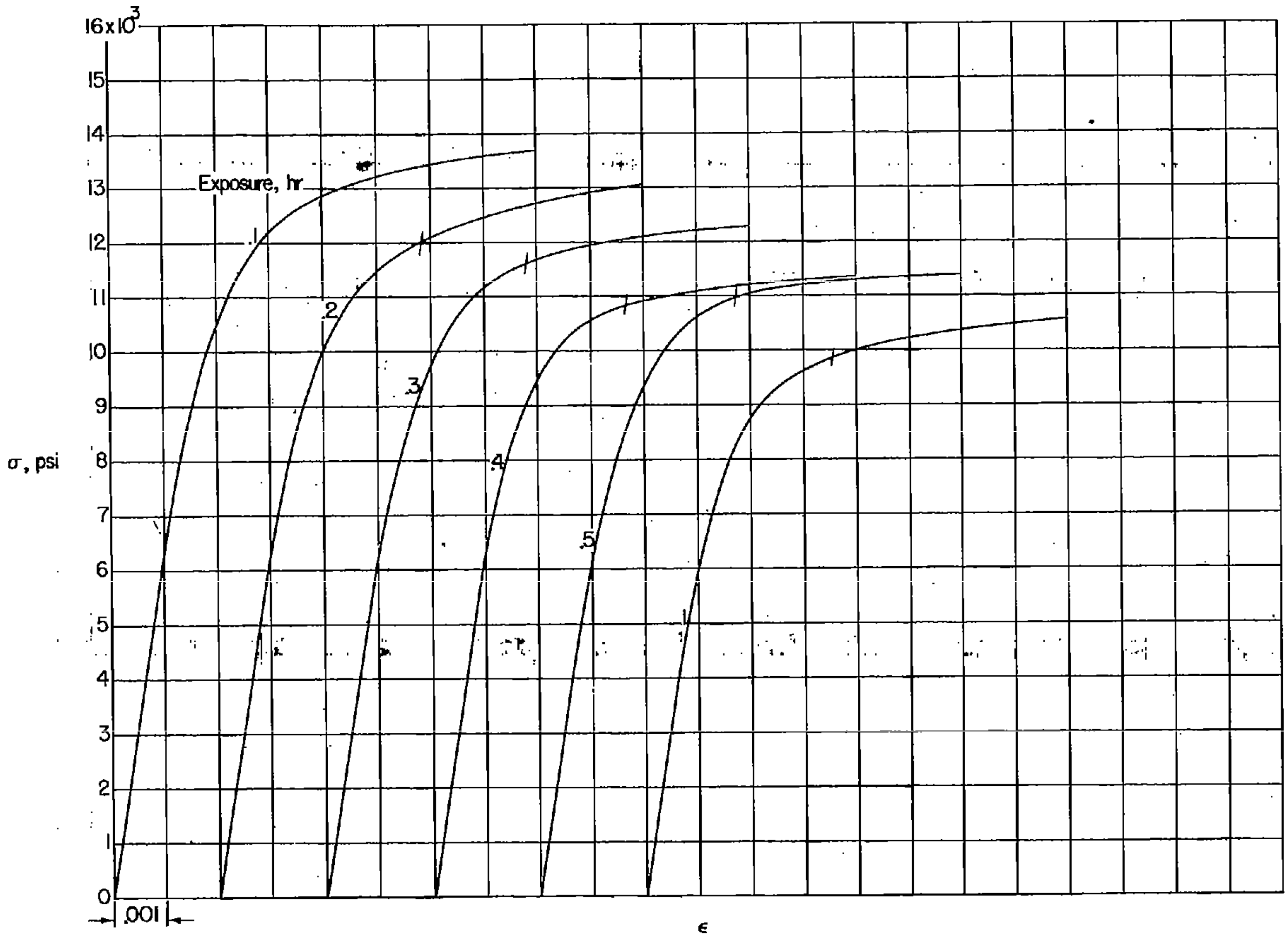


Figure 14.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 650° F.

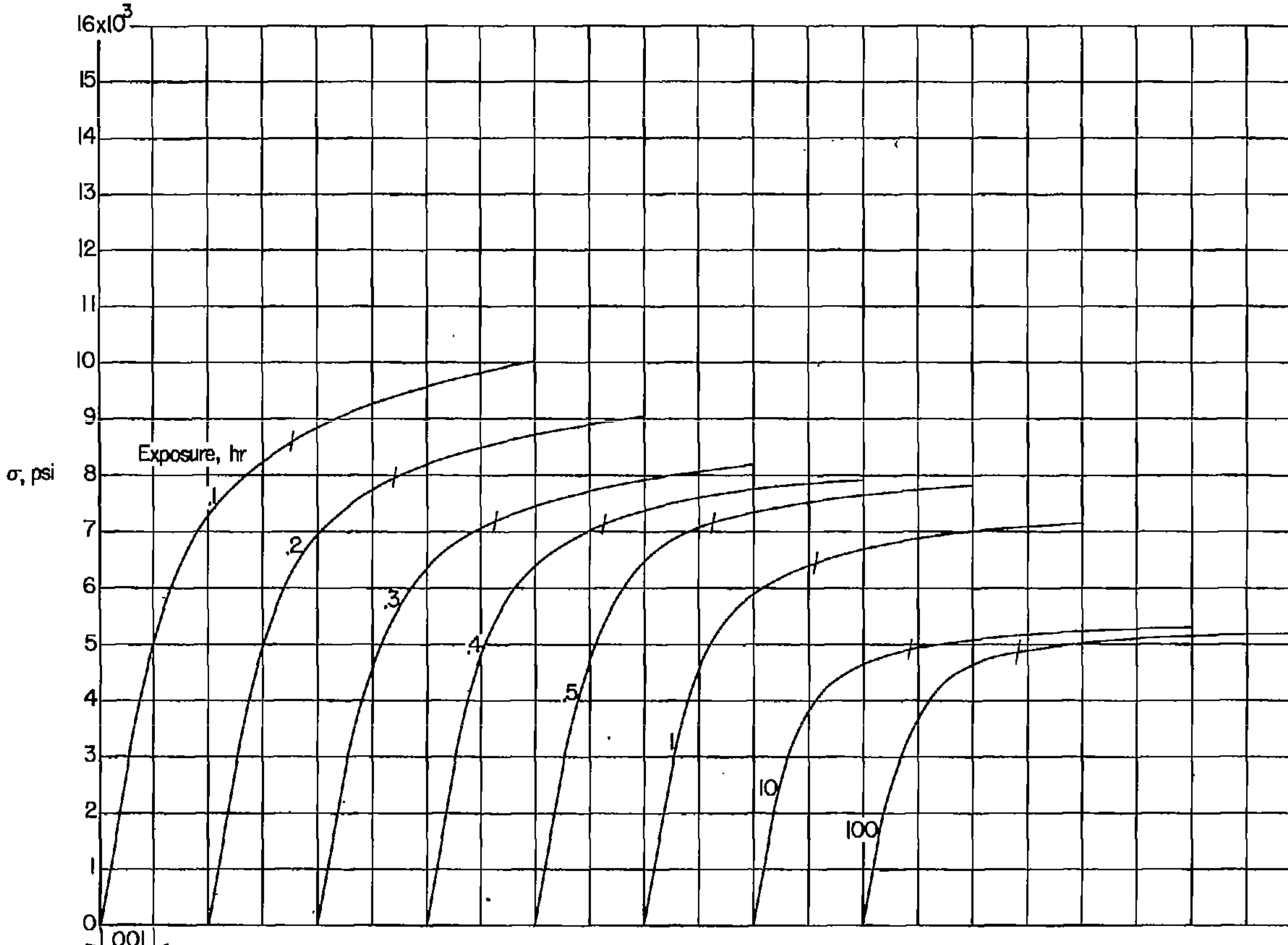


Figure 15.- Compressive stress-strain curves for 2024-T3 aluminum-alloy sheet at 700° F.

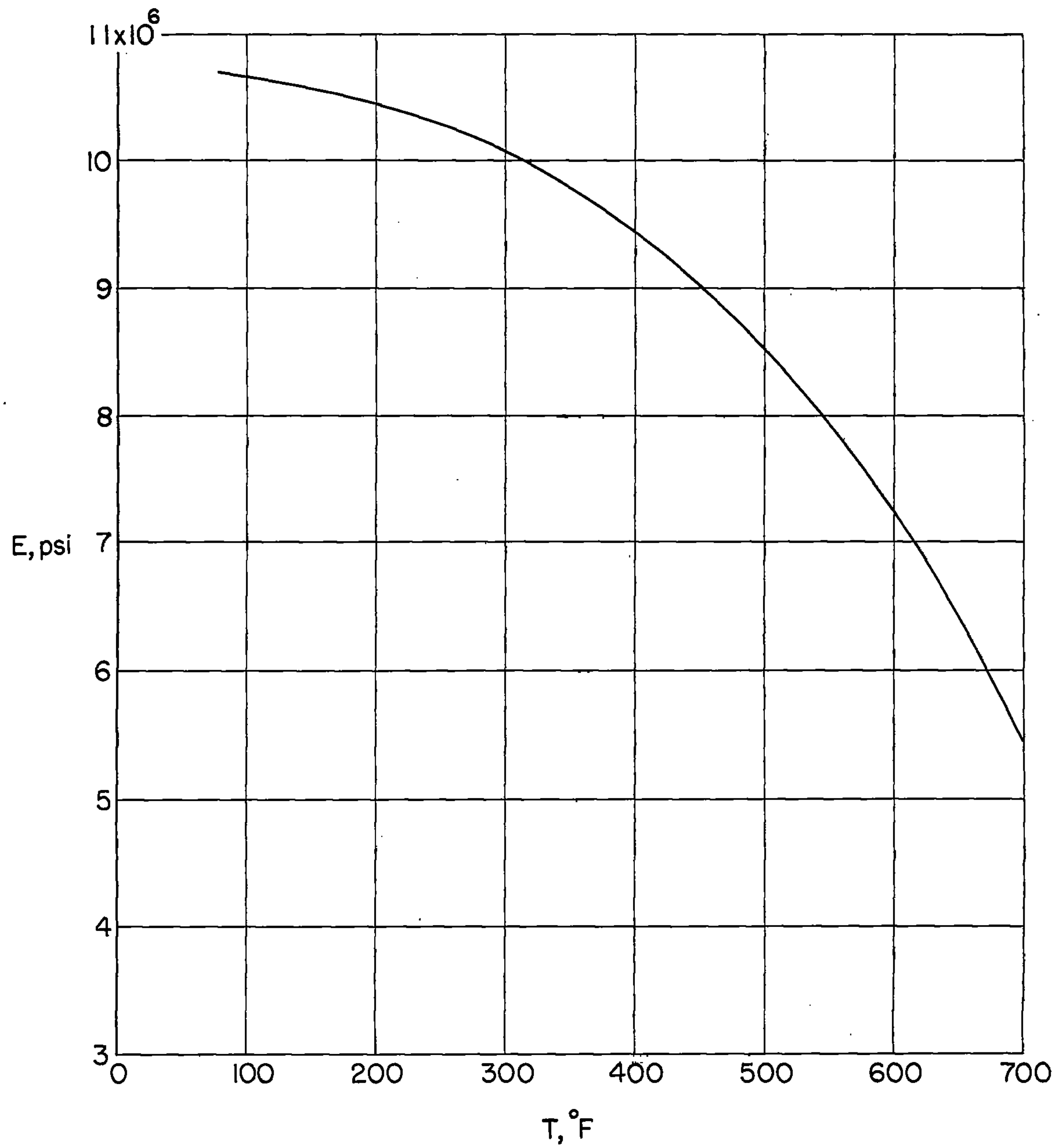
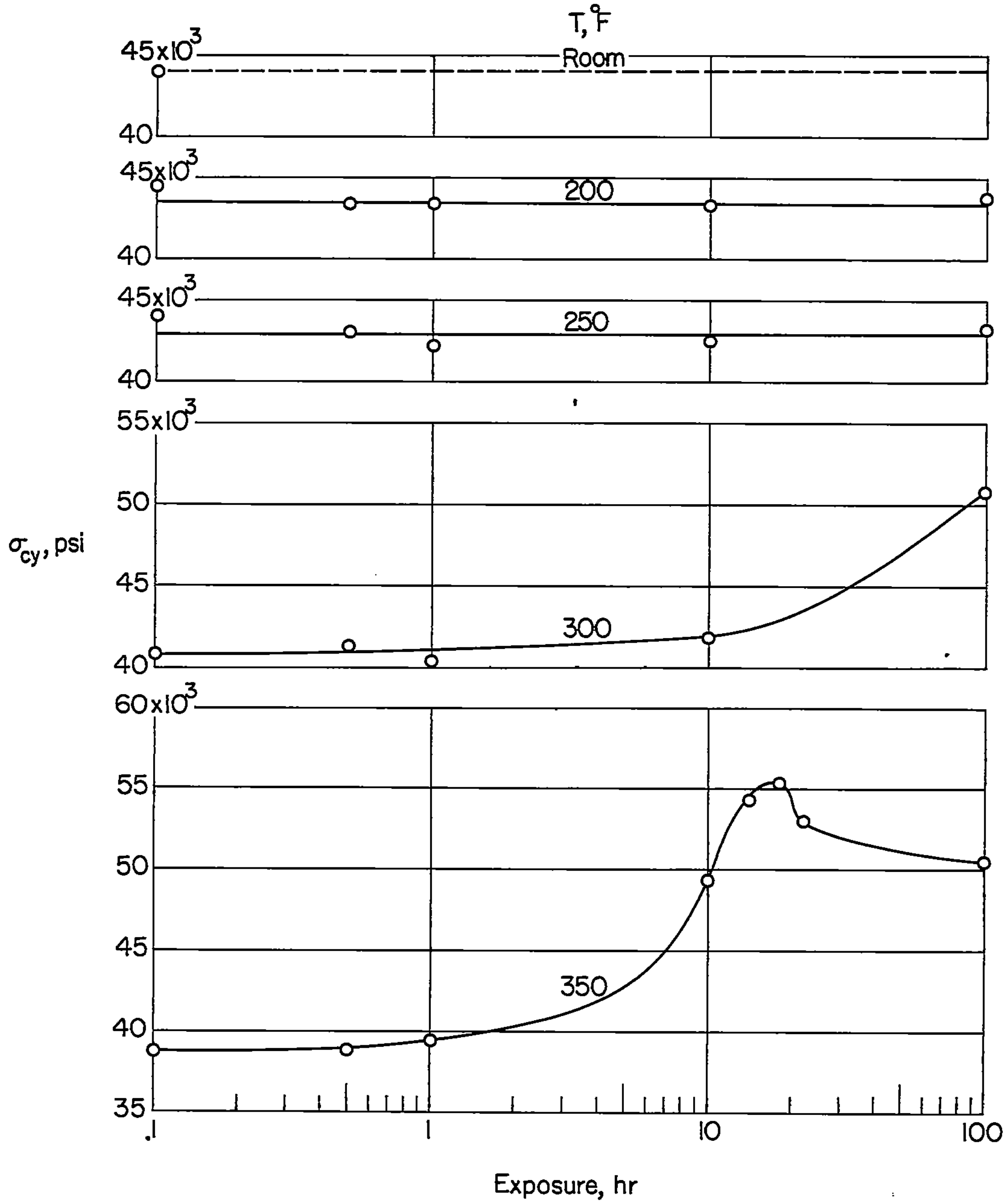
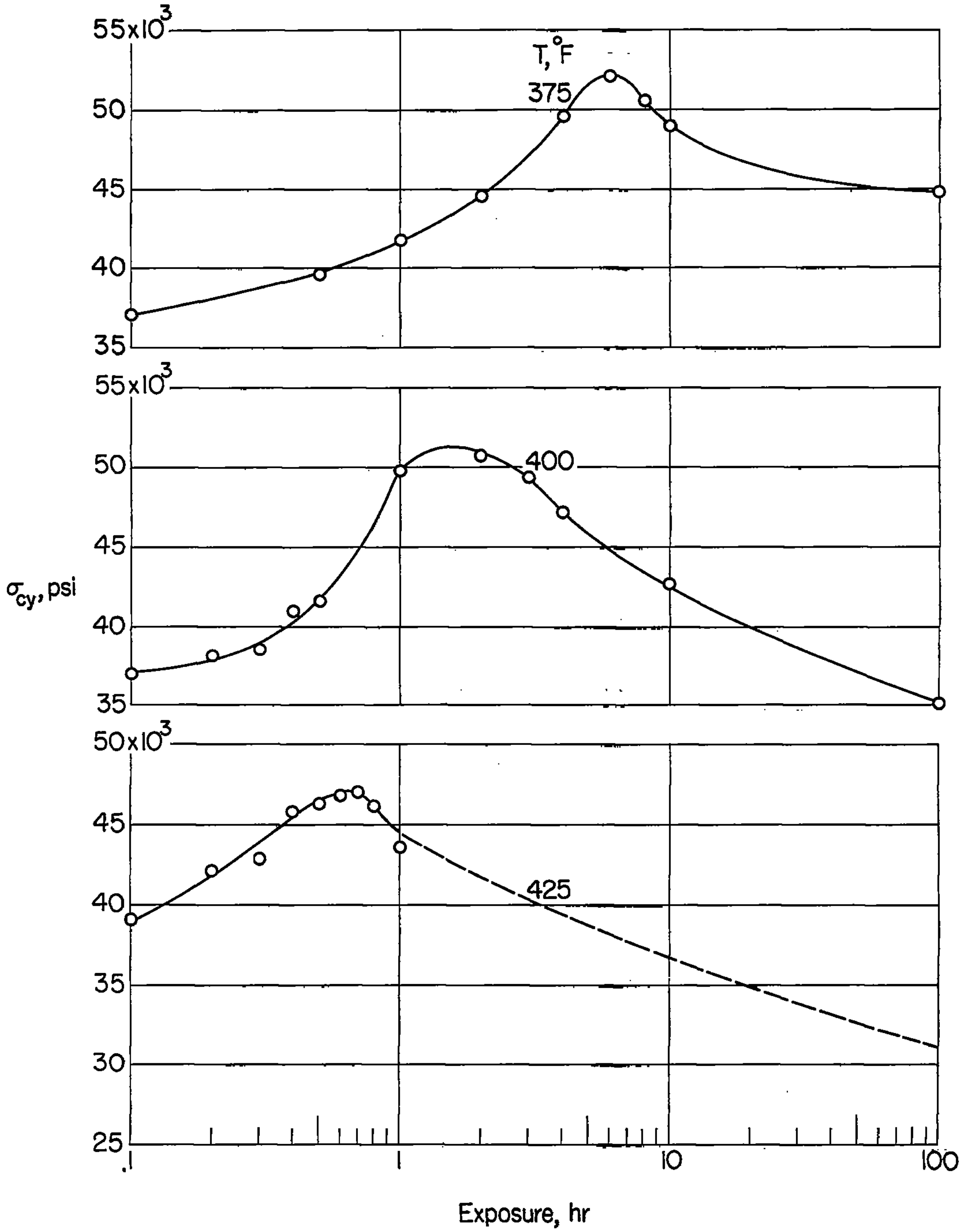


Figure 16.- Effect of temperature on Young's modulus for 2024-T3 aluminum-alloy sheet.



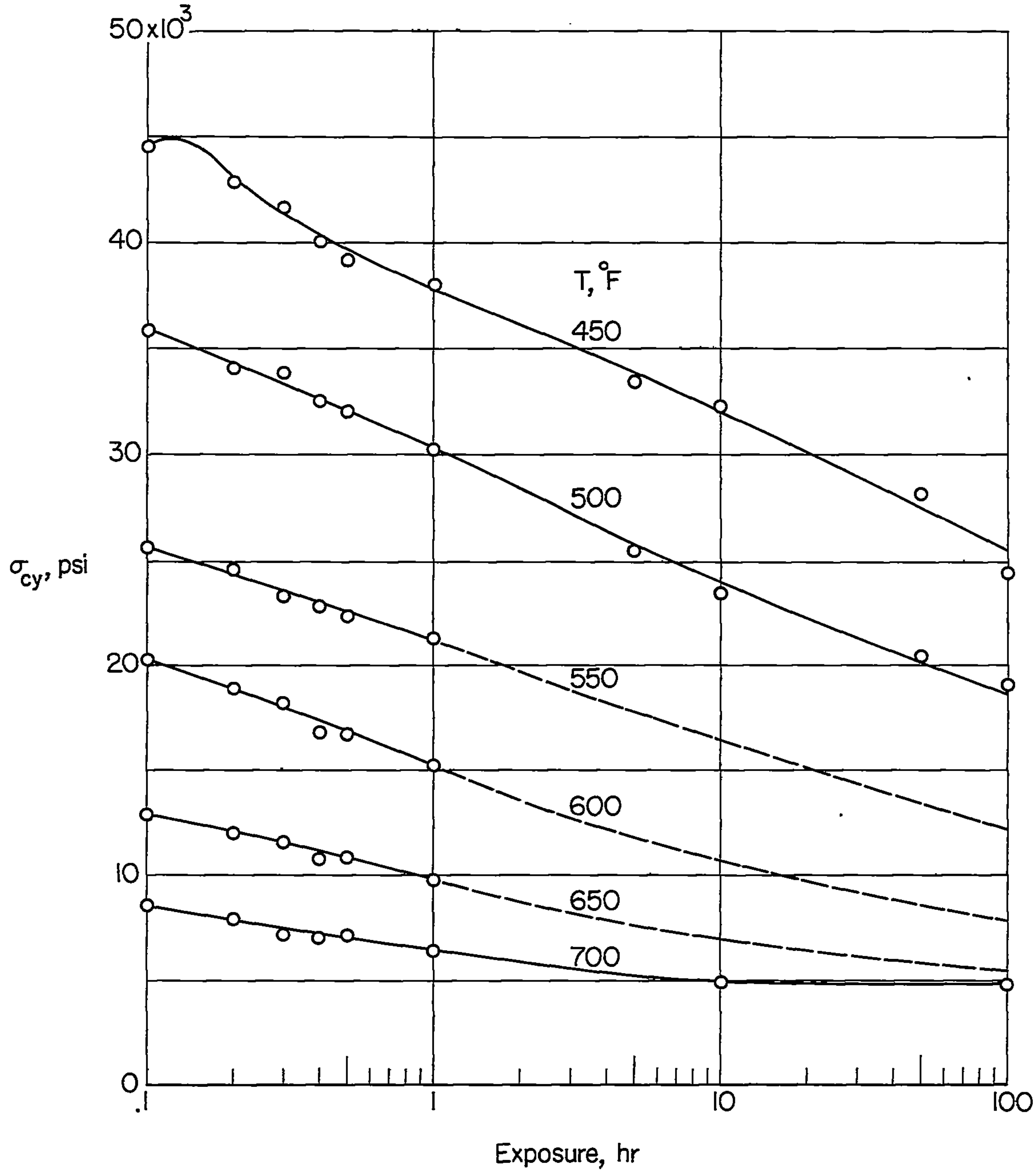
(a) Room temperature to 350° F.

Figure 17.- Effect of temperature and exposure time on the 0.2-percent-offset compressive yield stress for 2024-T3 aluminum-alloy sheet. (Dashed portions of curves indicate estimated values obtained from fig. 18.)



(b) 375° to 425° F.

Figure 17.- Continued.



(c) 450° to 700° F.

Figure 17.- Concluded.

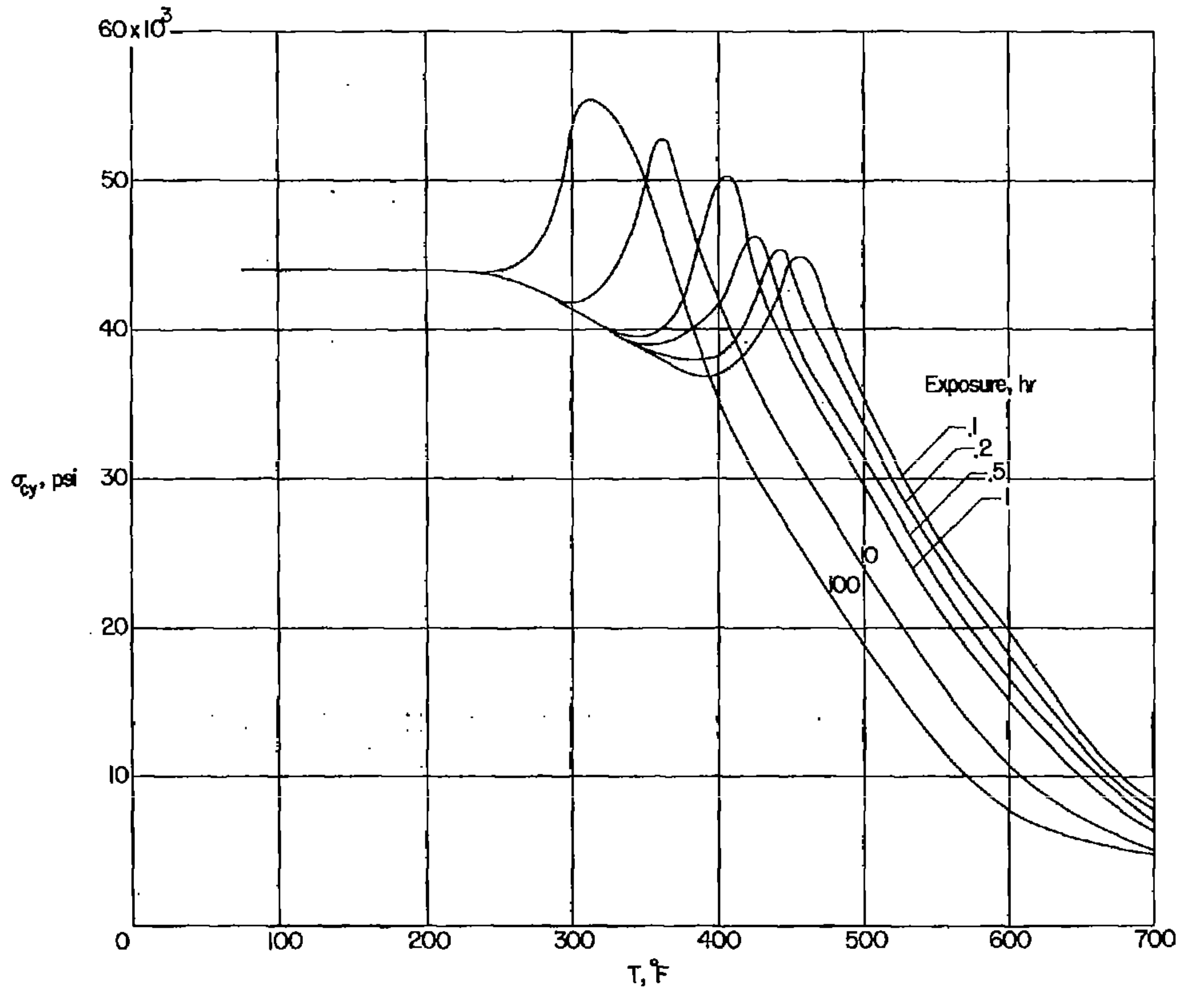


Figure 18.- Effect of temperature and exposure time on the 0.2-percent-offset compressive yield stress for 2024-T3 aluminum-alloy sheet (obtained by cross-plotting data in fig. 17).

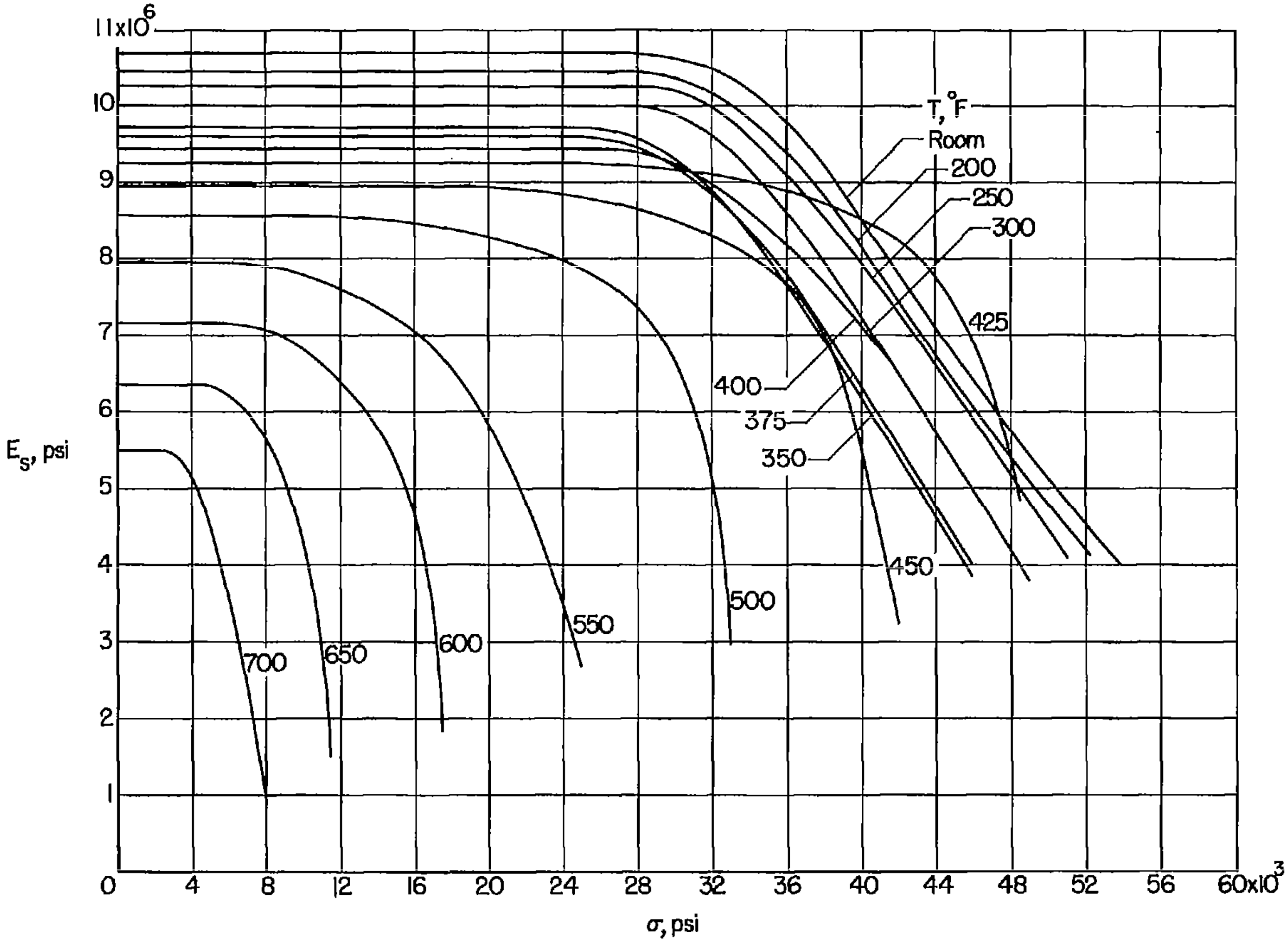


Figure 19.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet. 0.5-hour exposure.

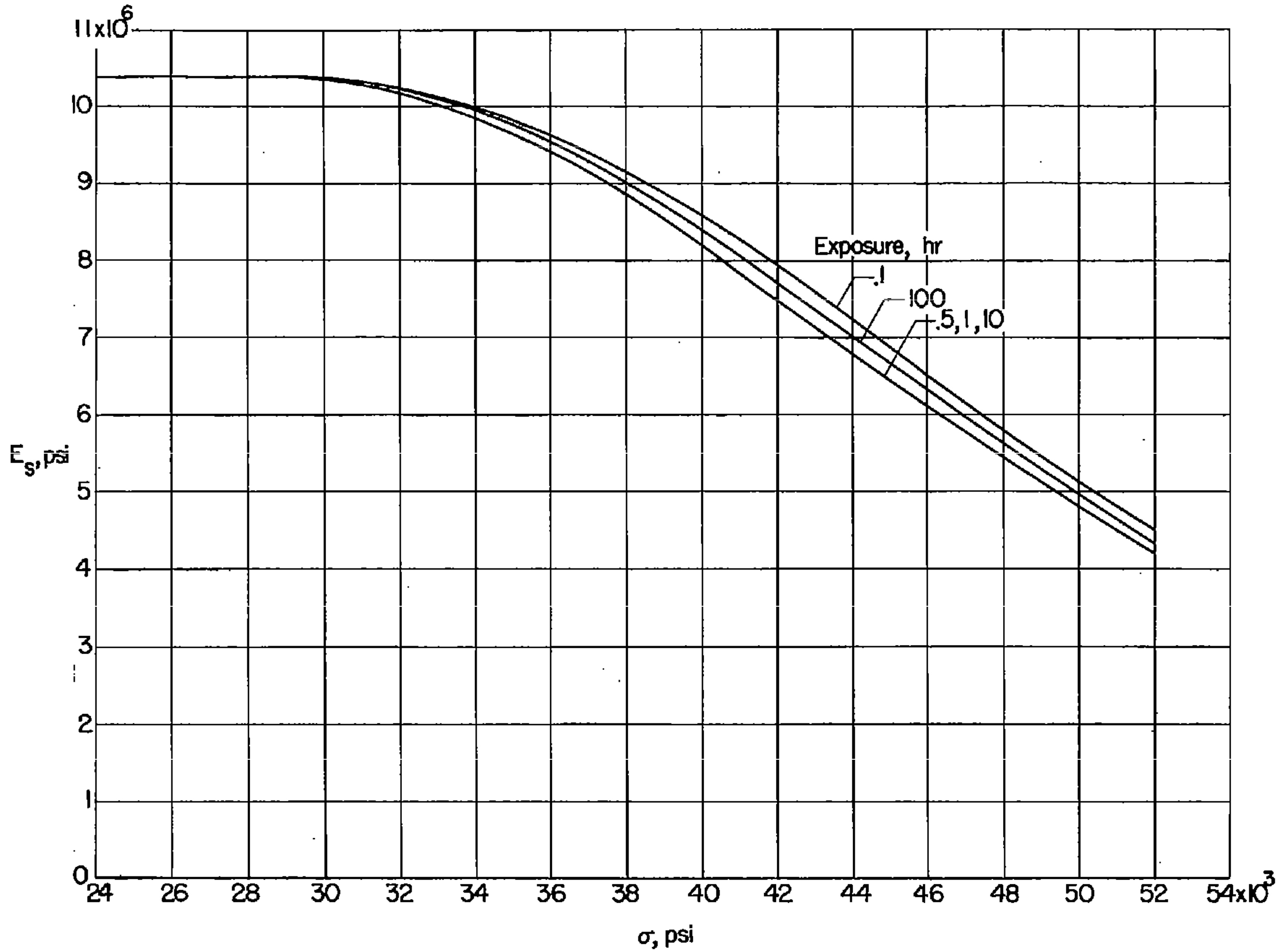


Figure 20.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 200° F.

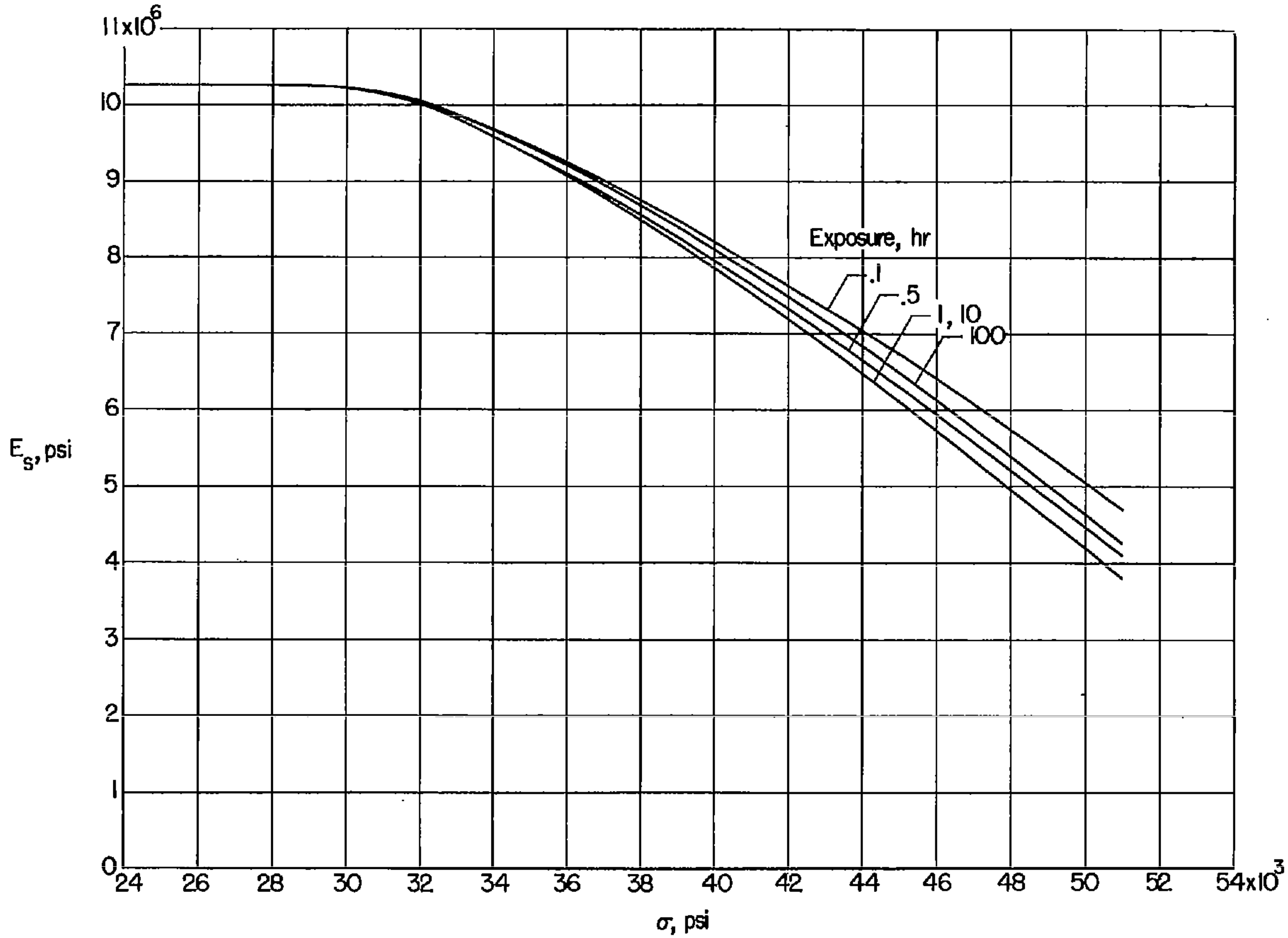


Figure 21.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 250° F.

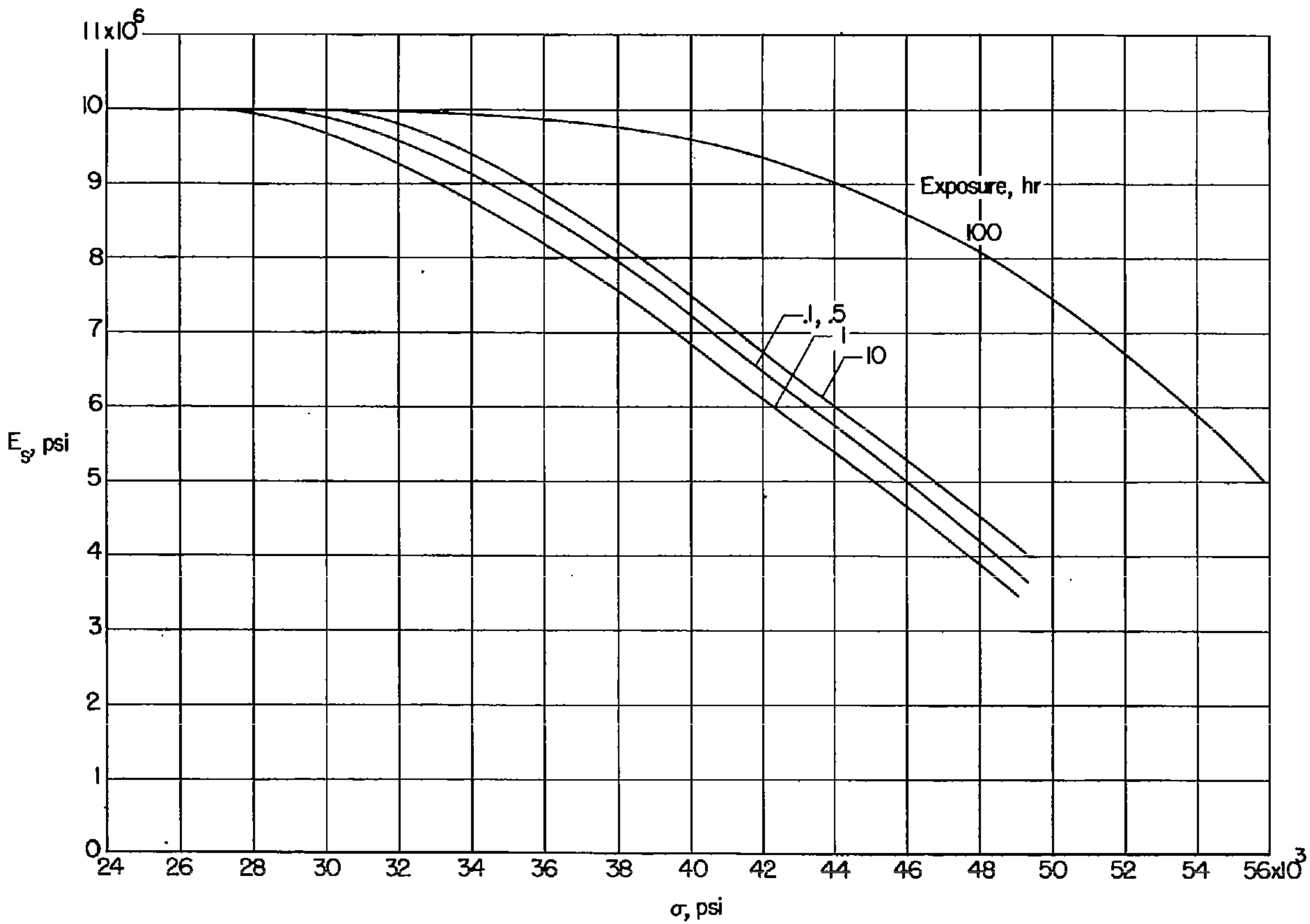


Figure 22.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 300° F.

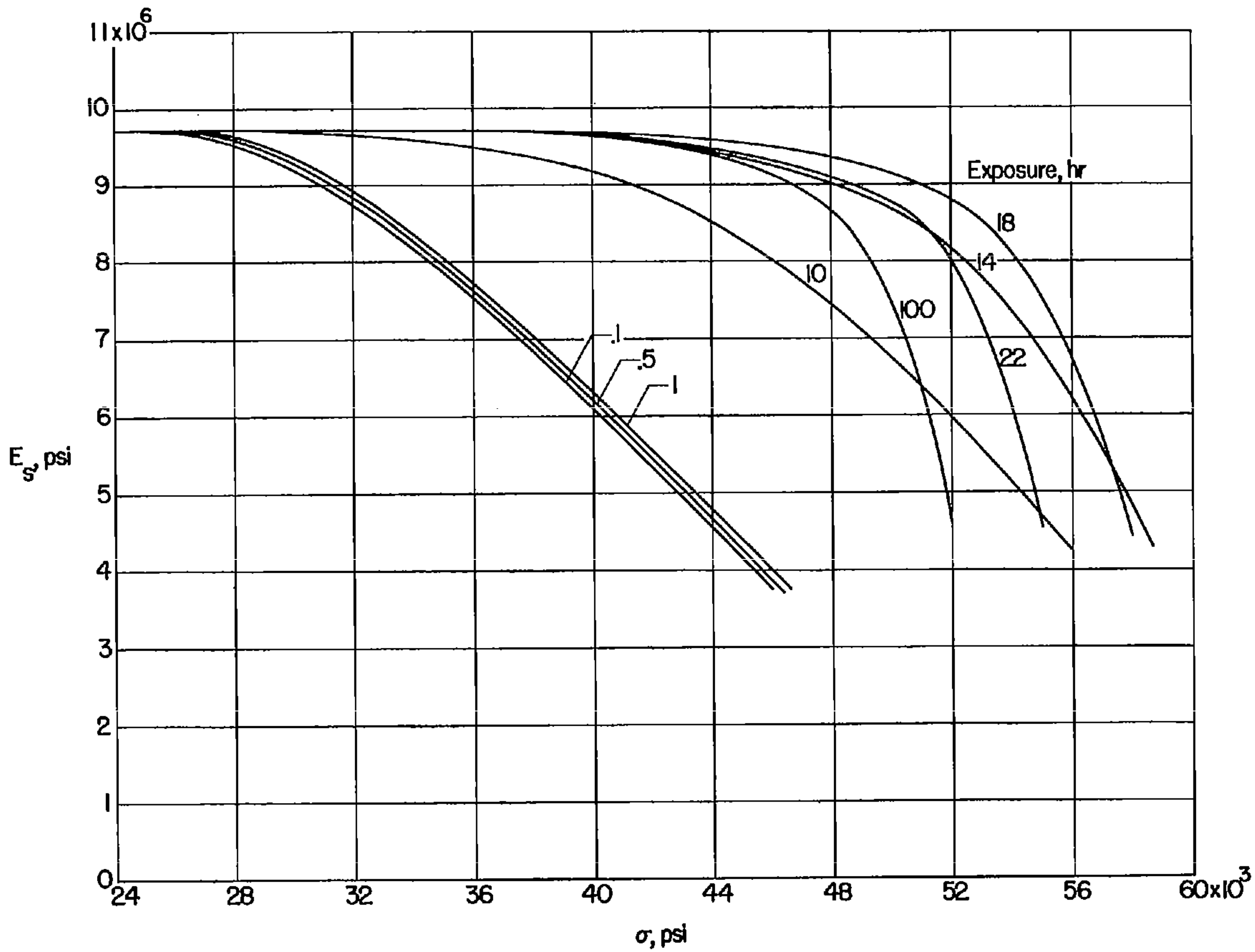


Figure 23.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 350° F.

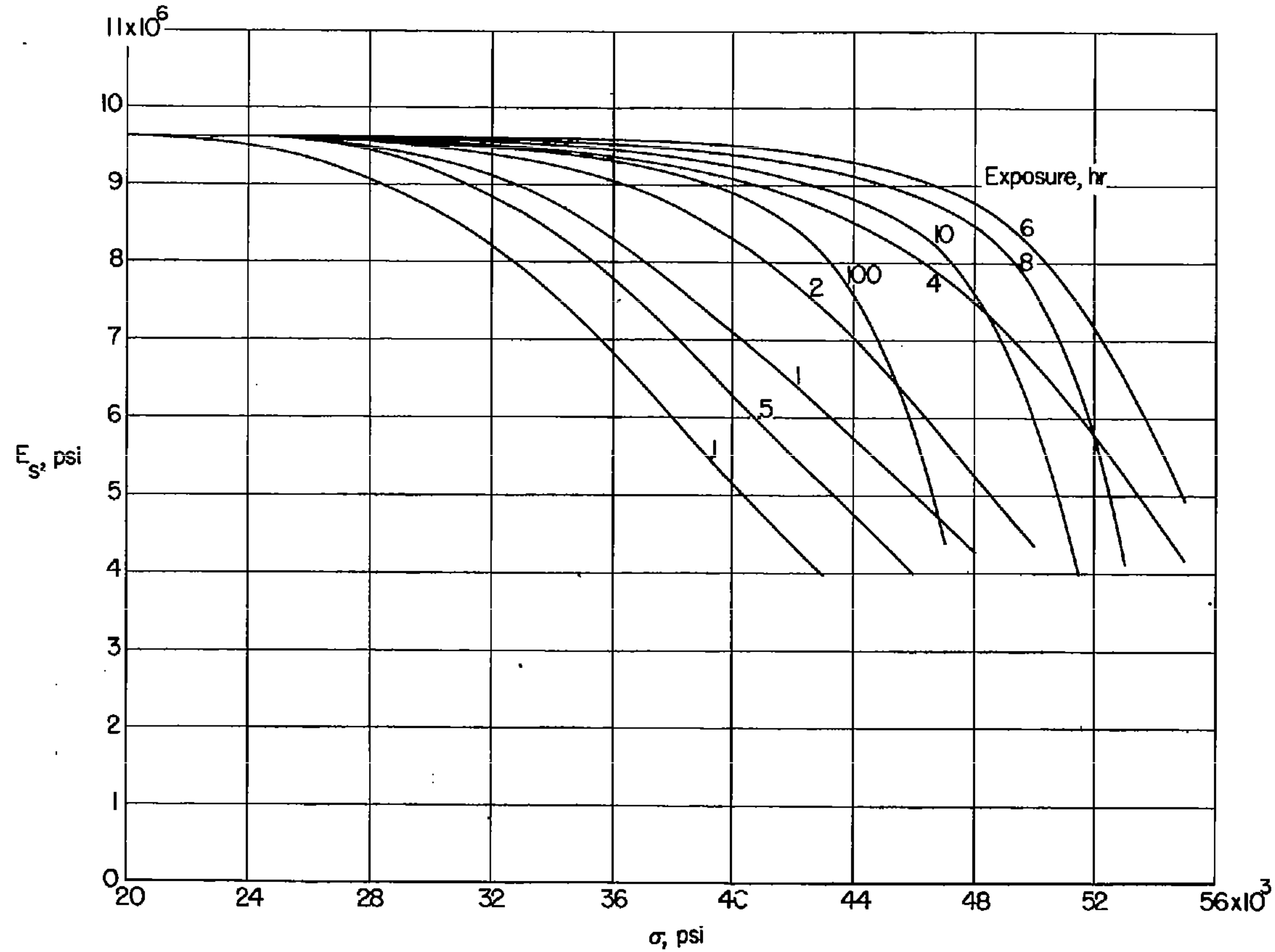


Figure 24.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 375° F.

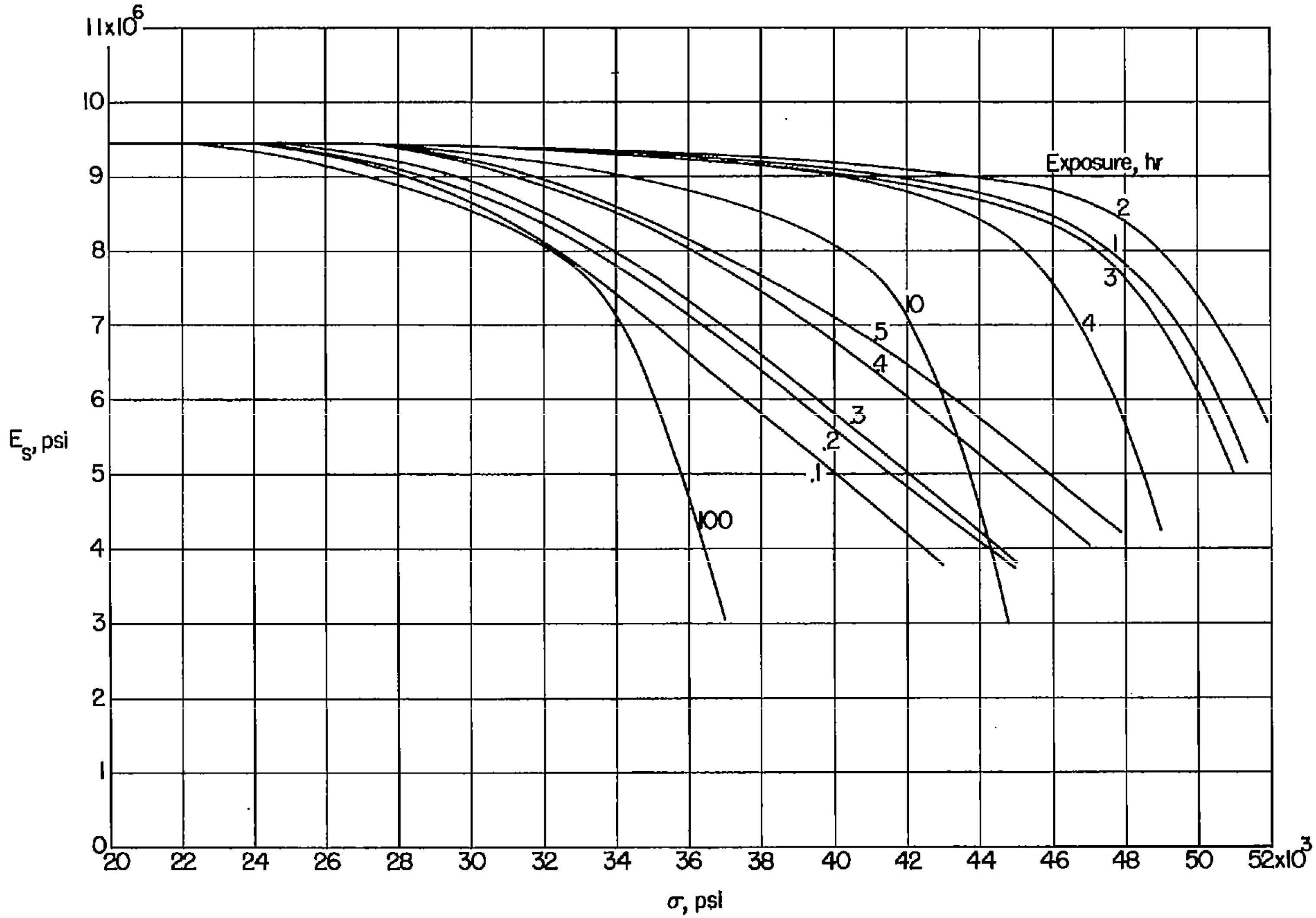


Figure 25.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 400° F.

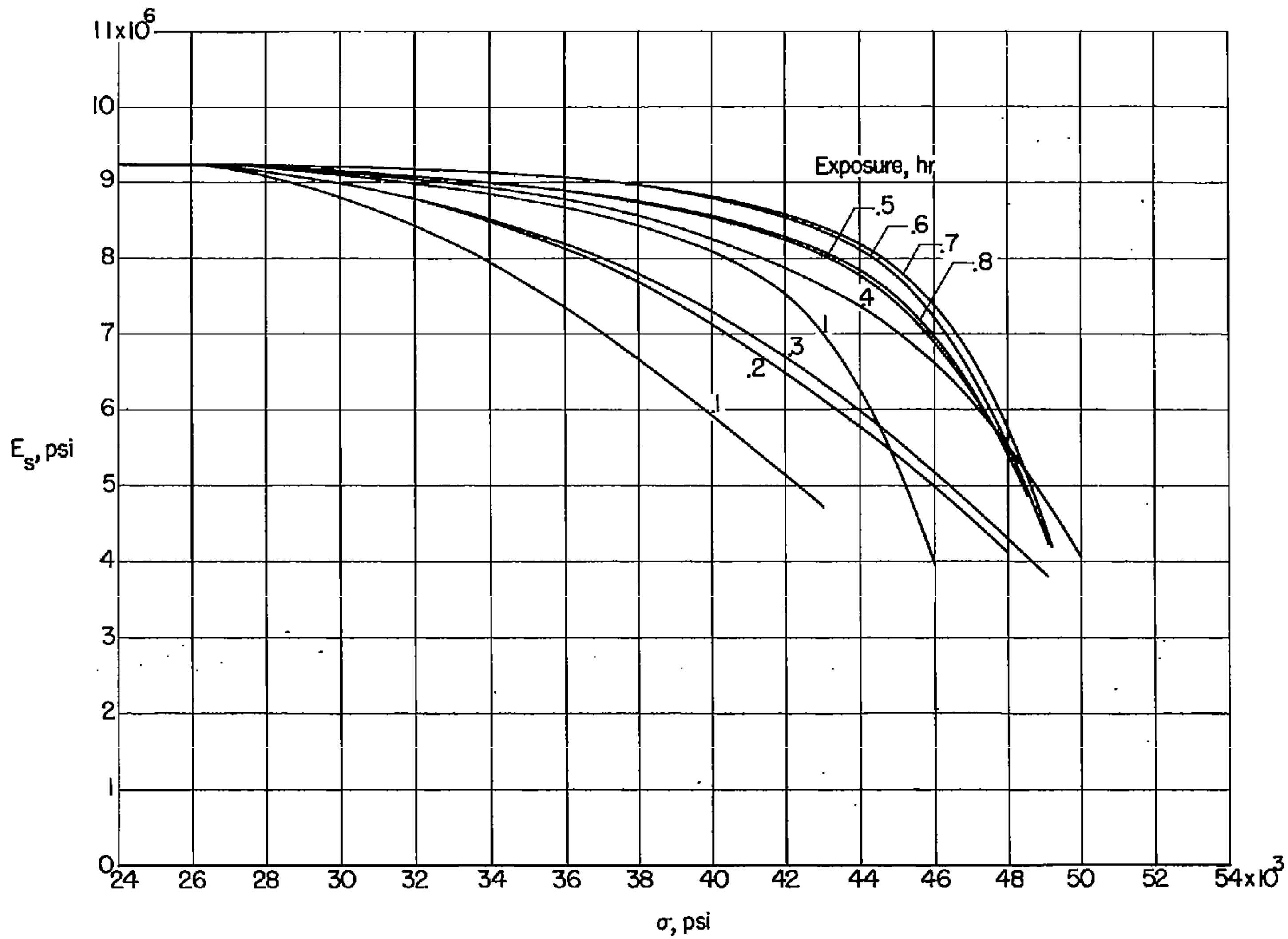


Figure 26.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 425° F.

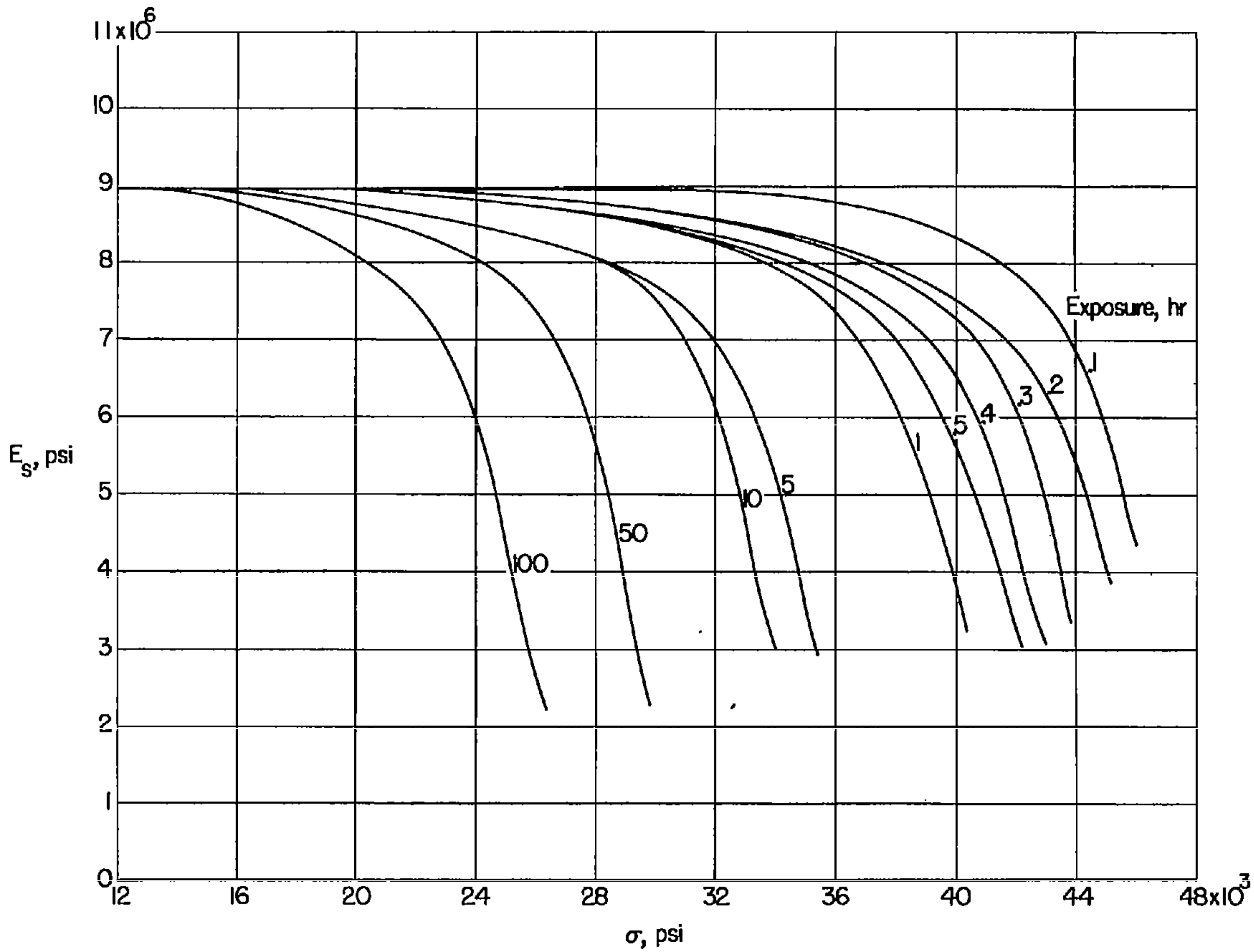


Figure 27.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 450° F.

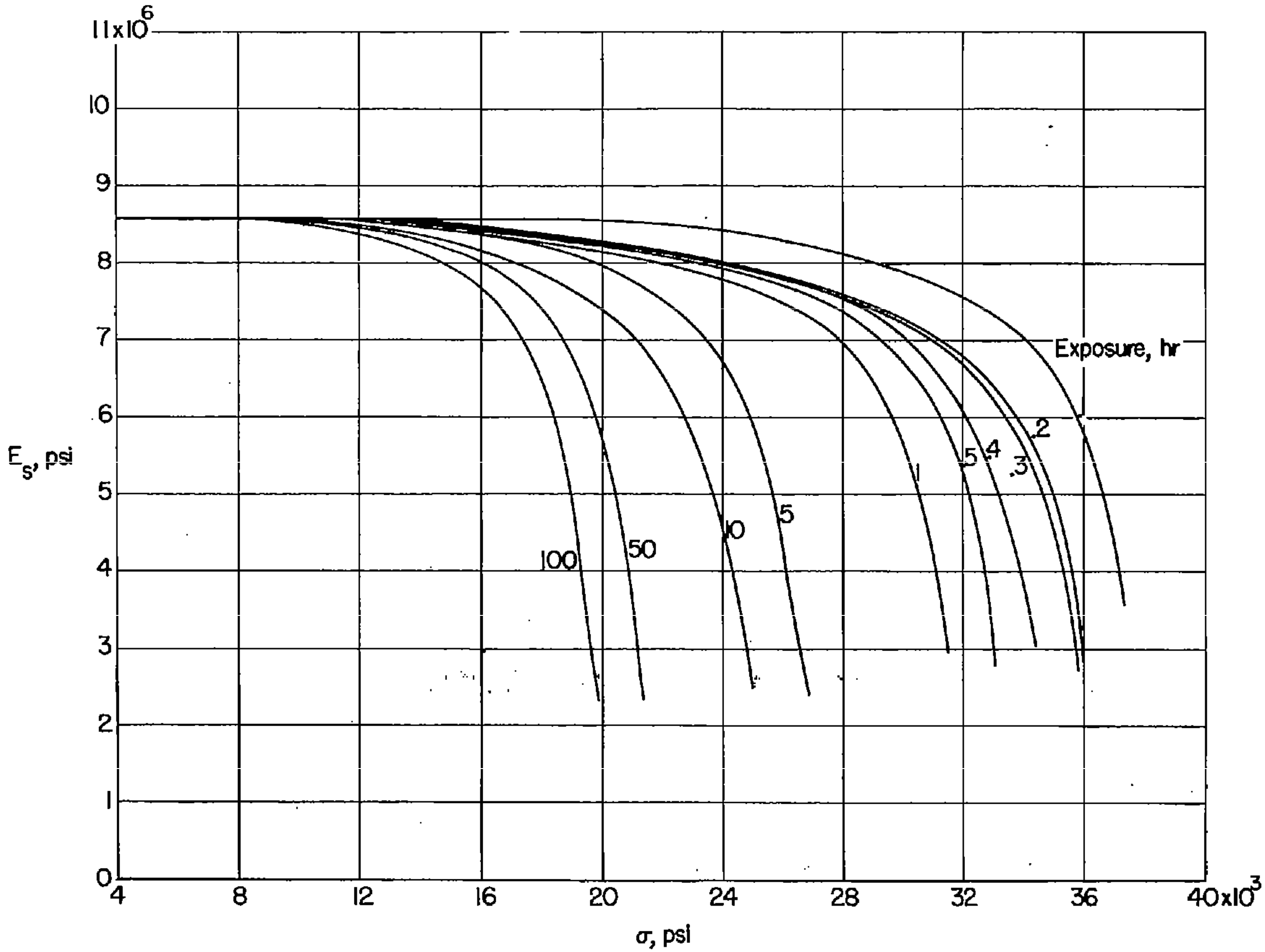


Figure 28.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 500° F.

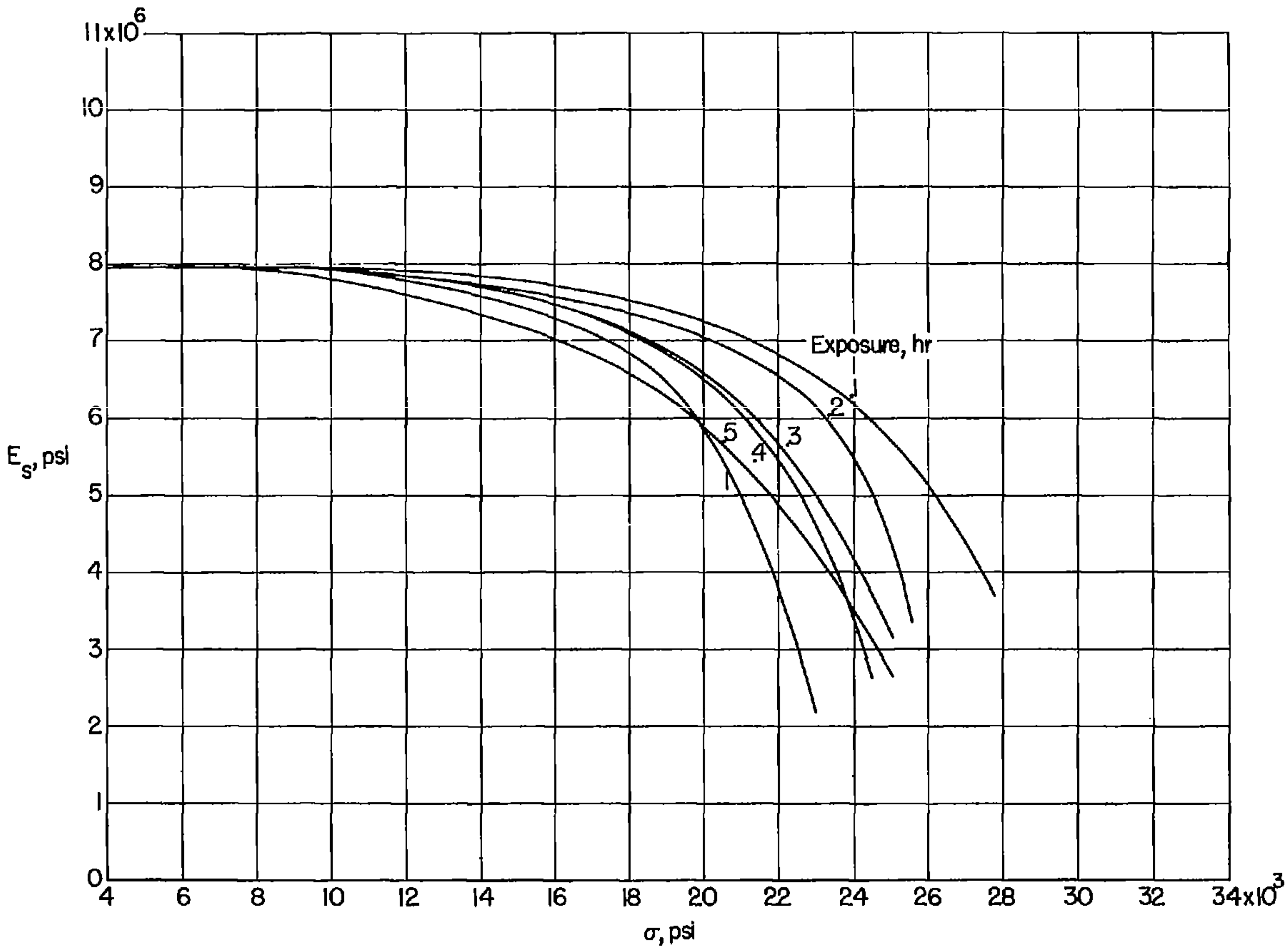


Figure 29.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 550° F.

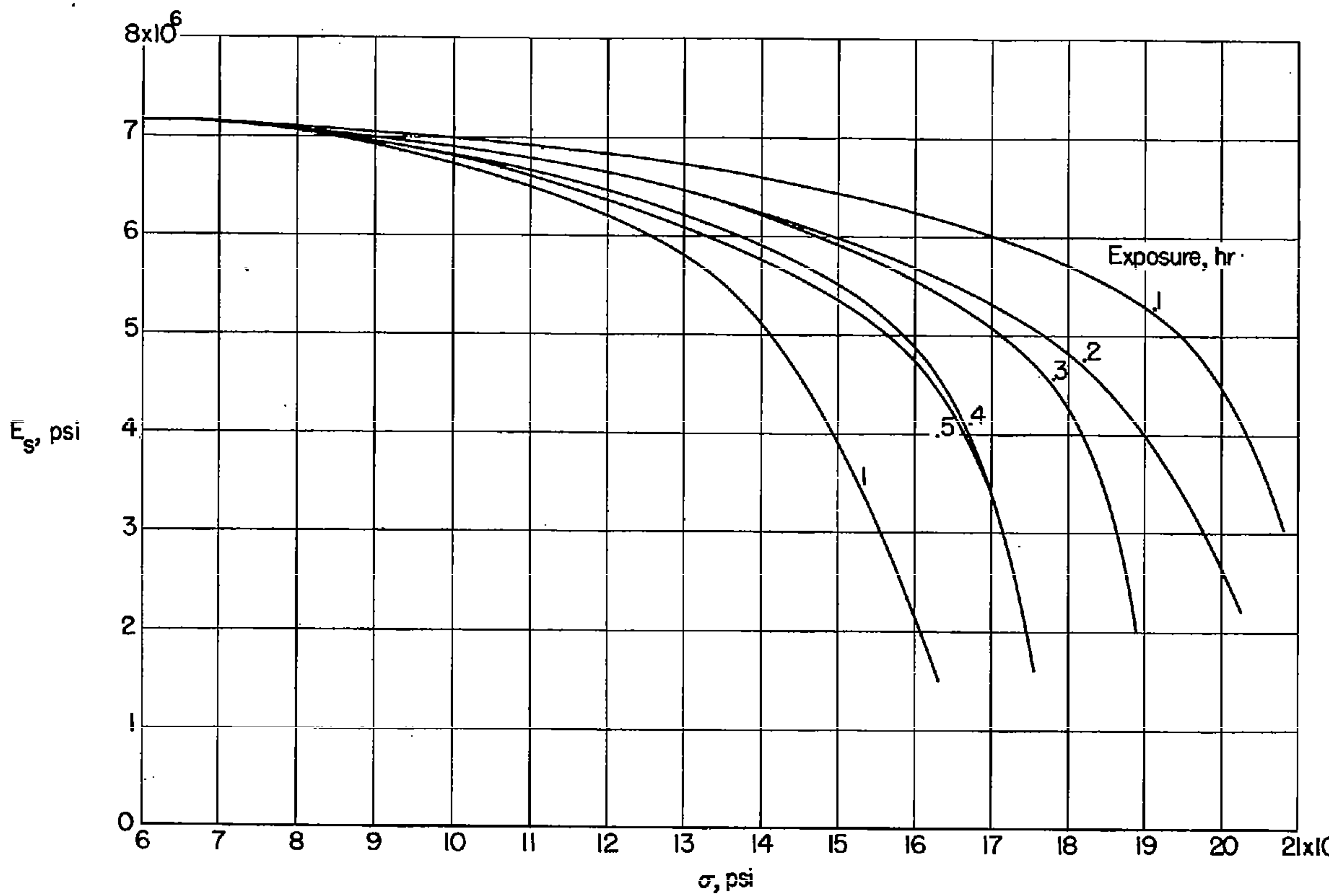


Figure 30.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 600° F.

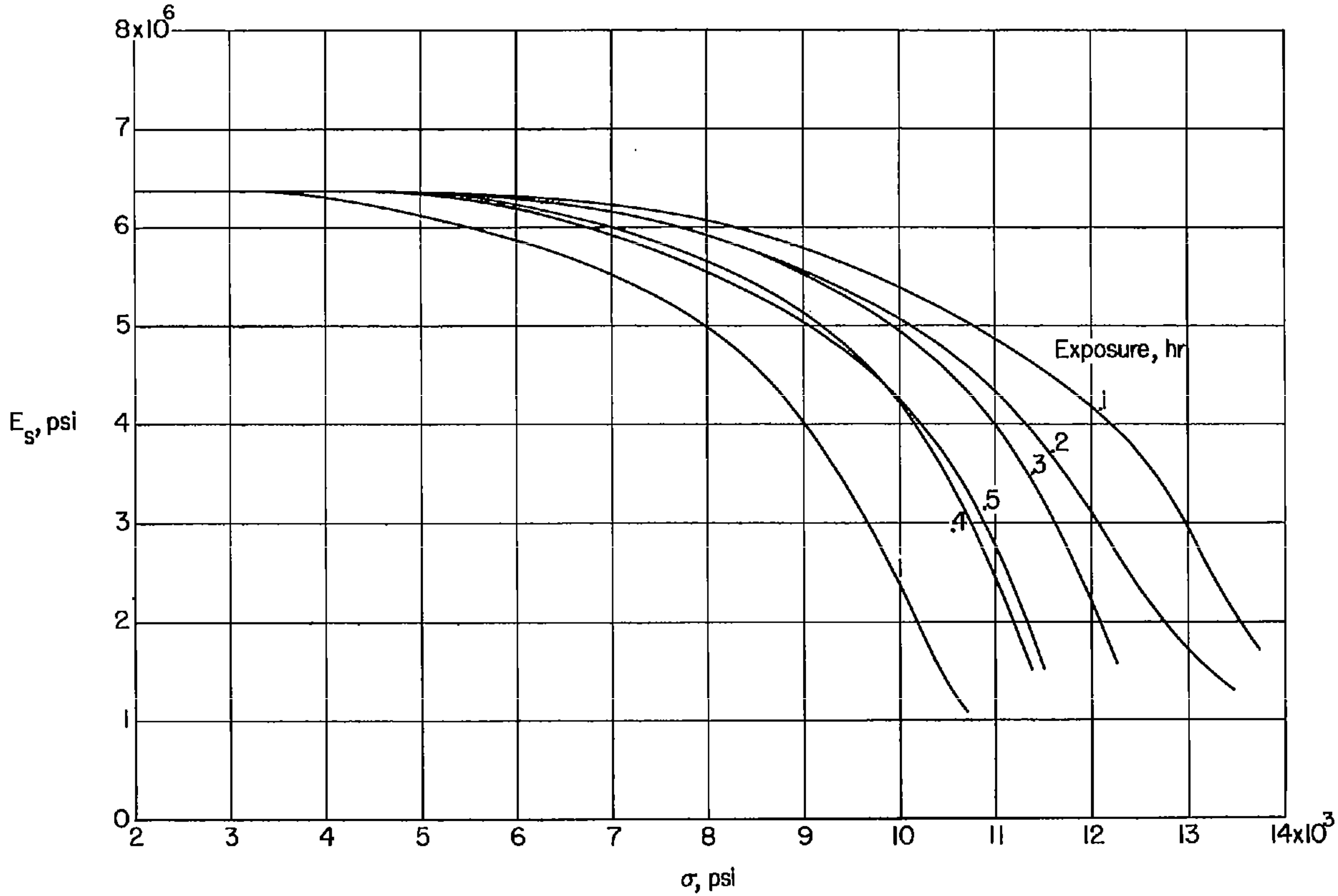


Figure 31.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 650° F.

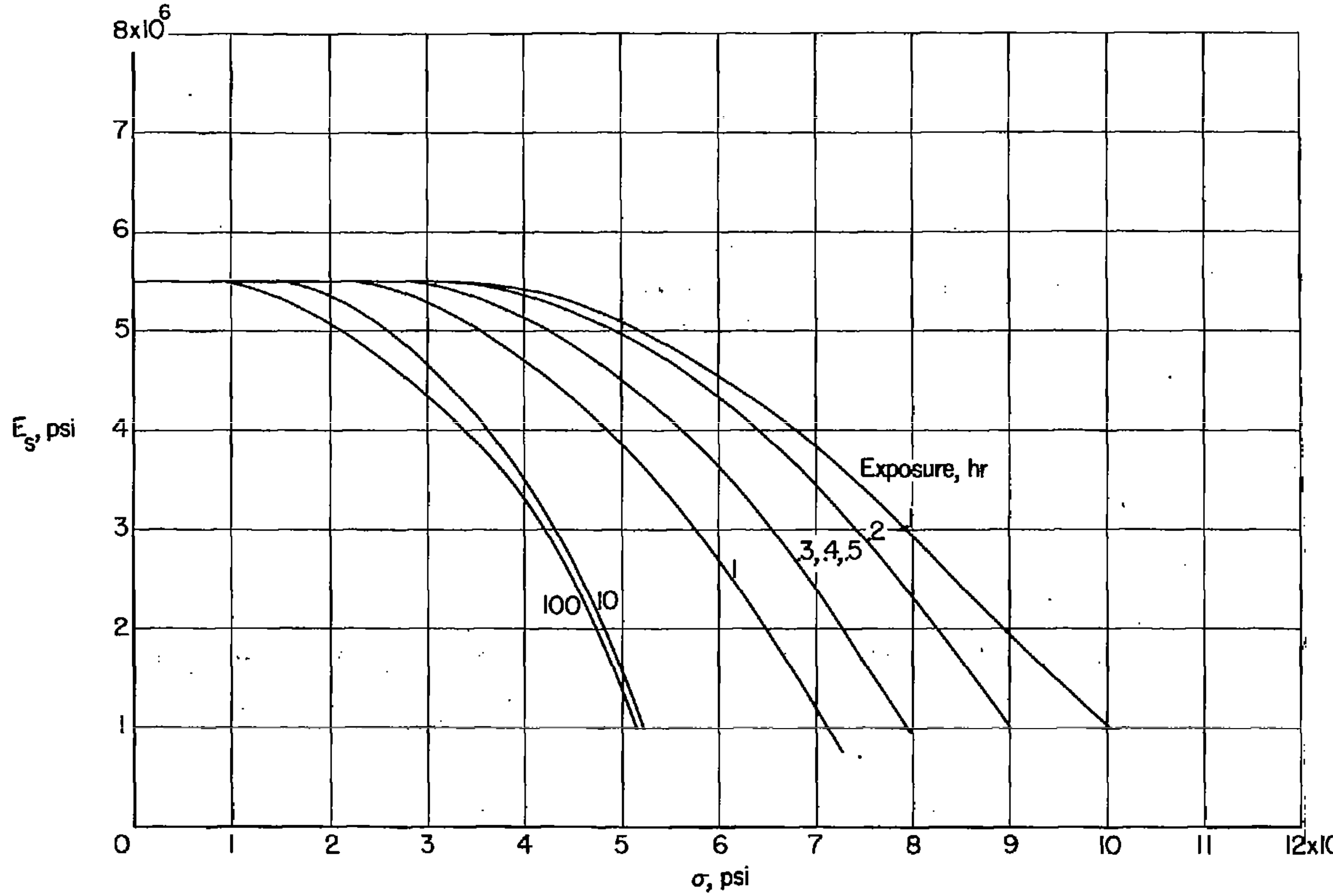


Figure 32.- Variation of secant modulus with stress for 2024-T3 aluminum-alloy sheet at 700° F.

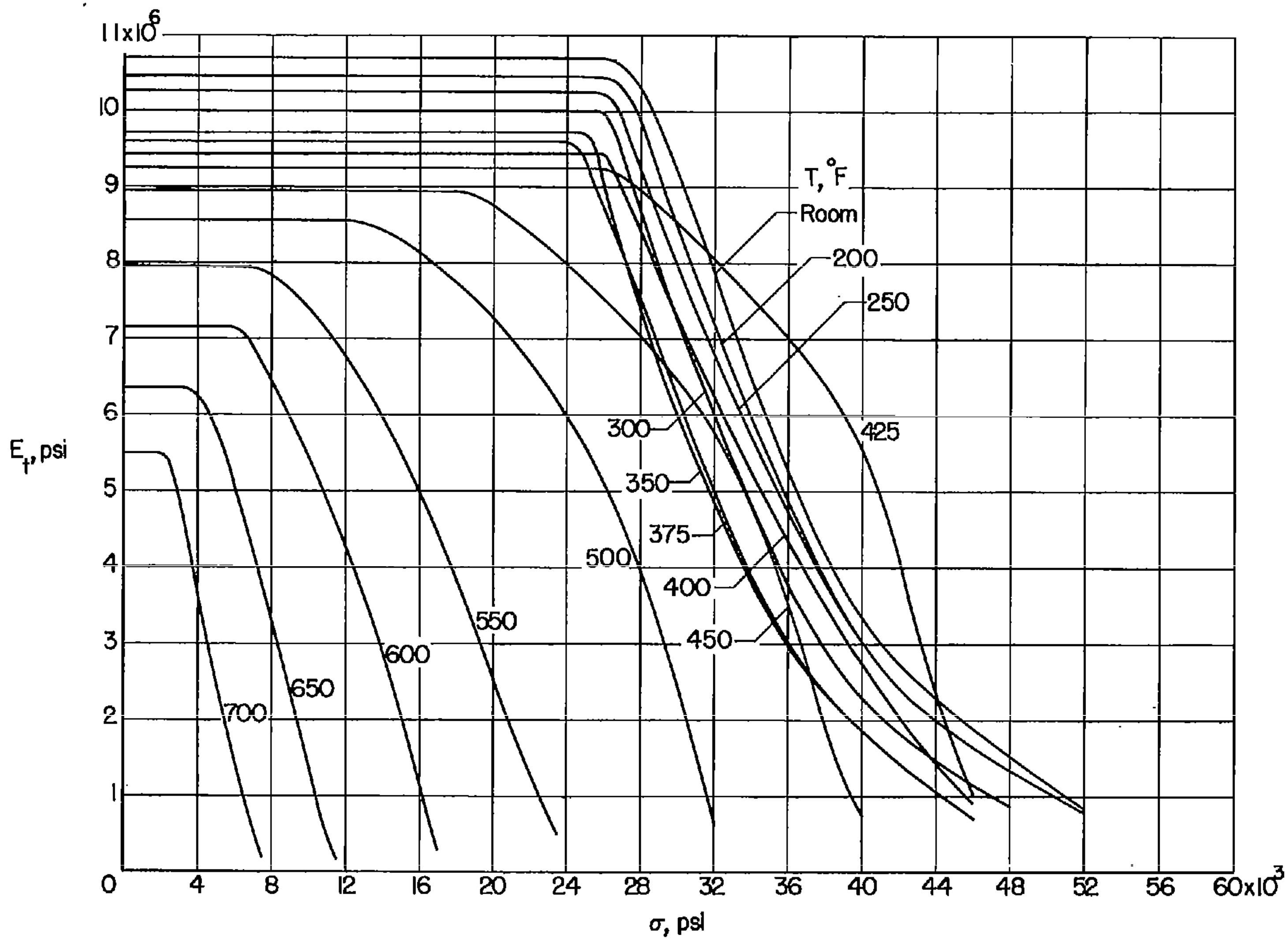


Figure 33.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet. 0.5-hour exposure.

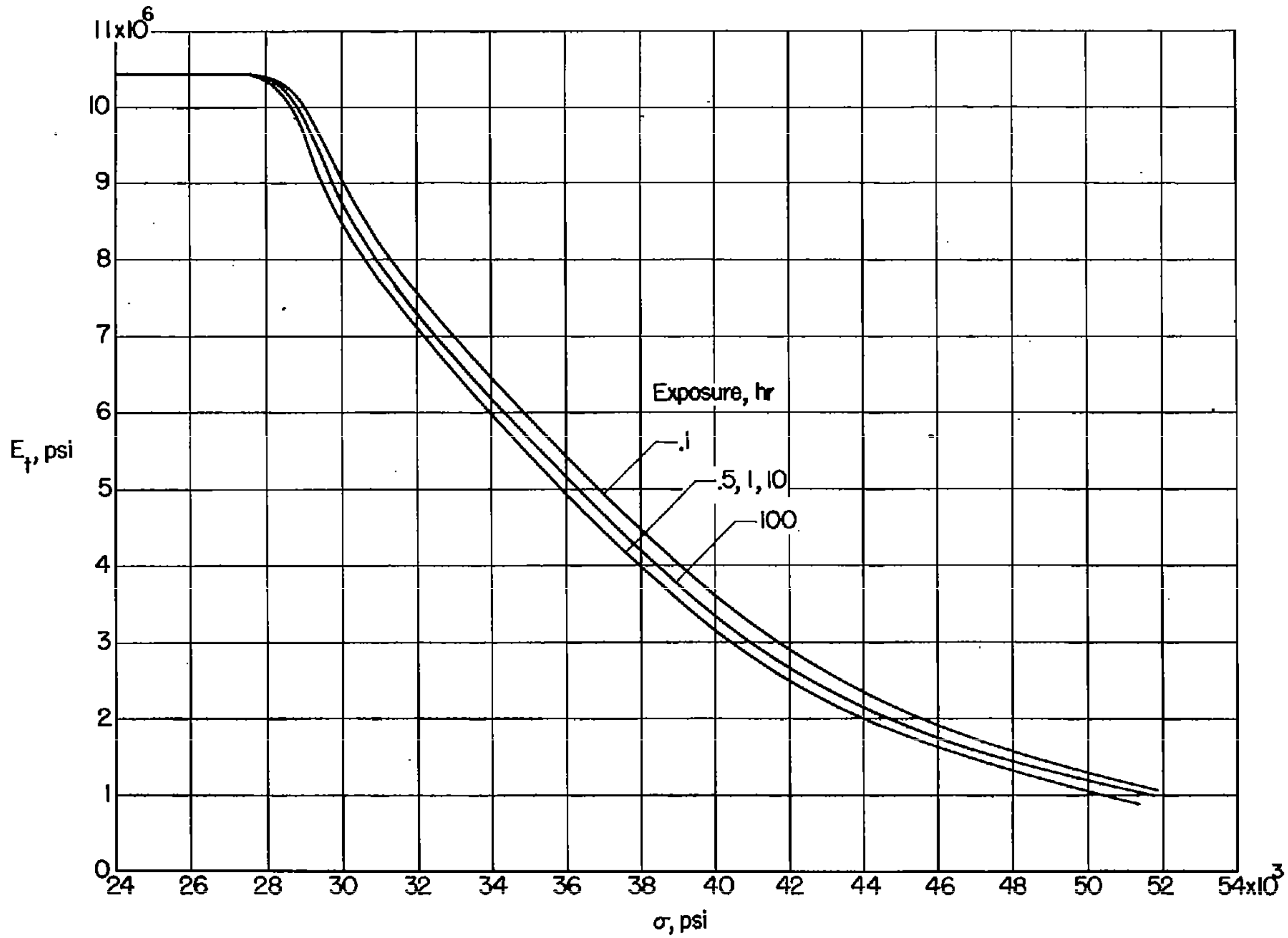


Figure 34.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 200° F.

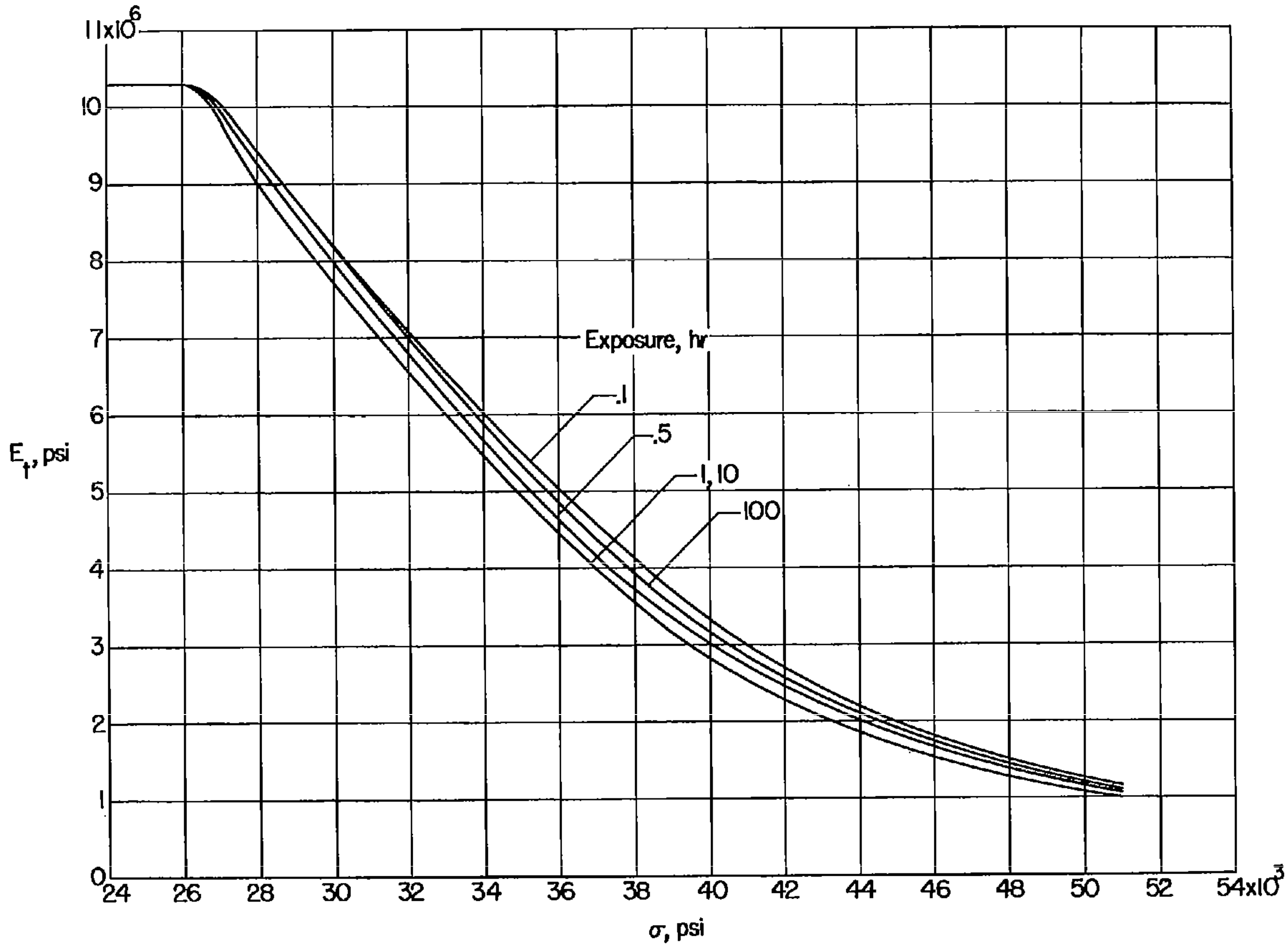


Figure 35.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 250° F.

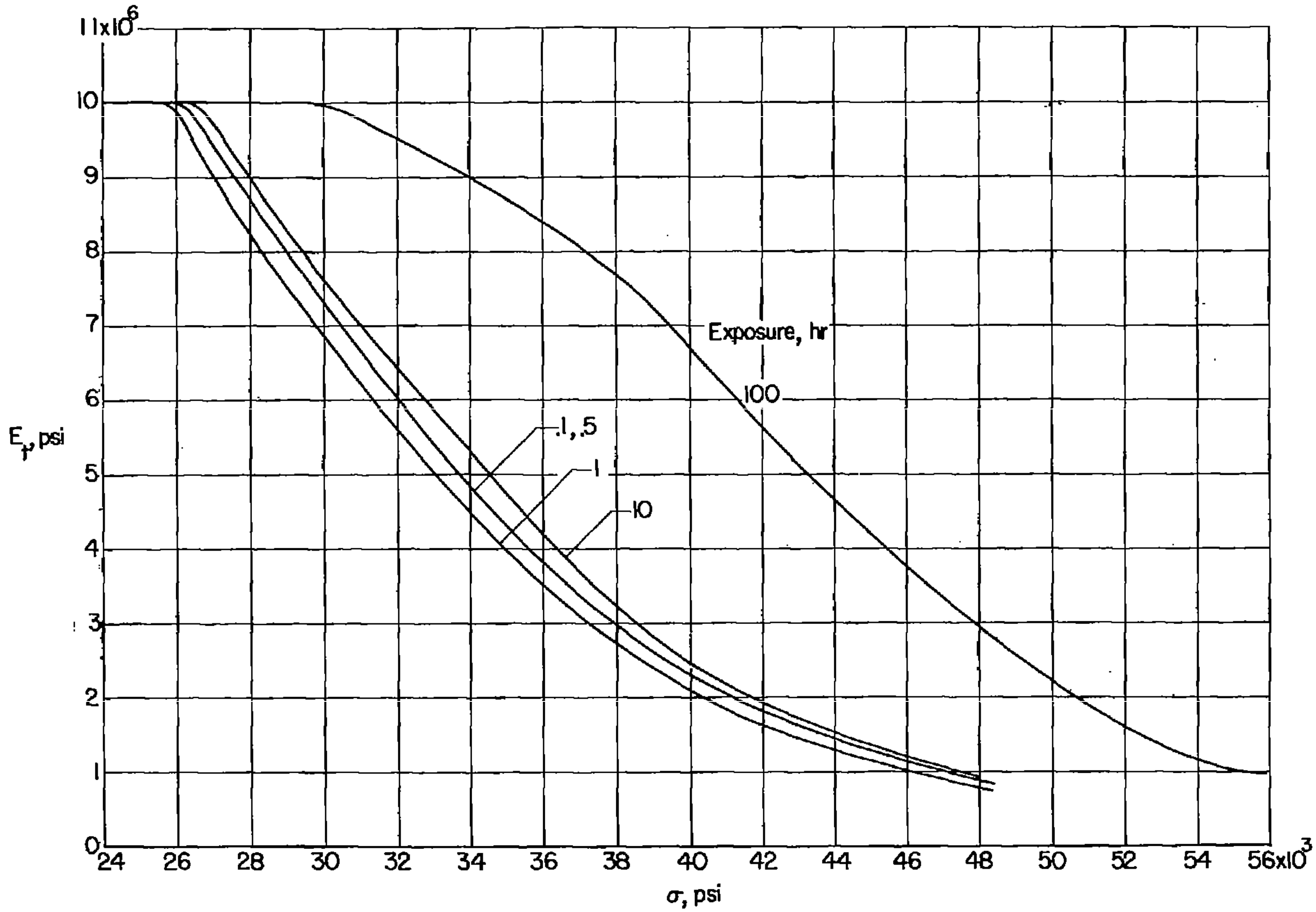


Figure 36.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 300° F.

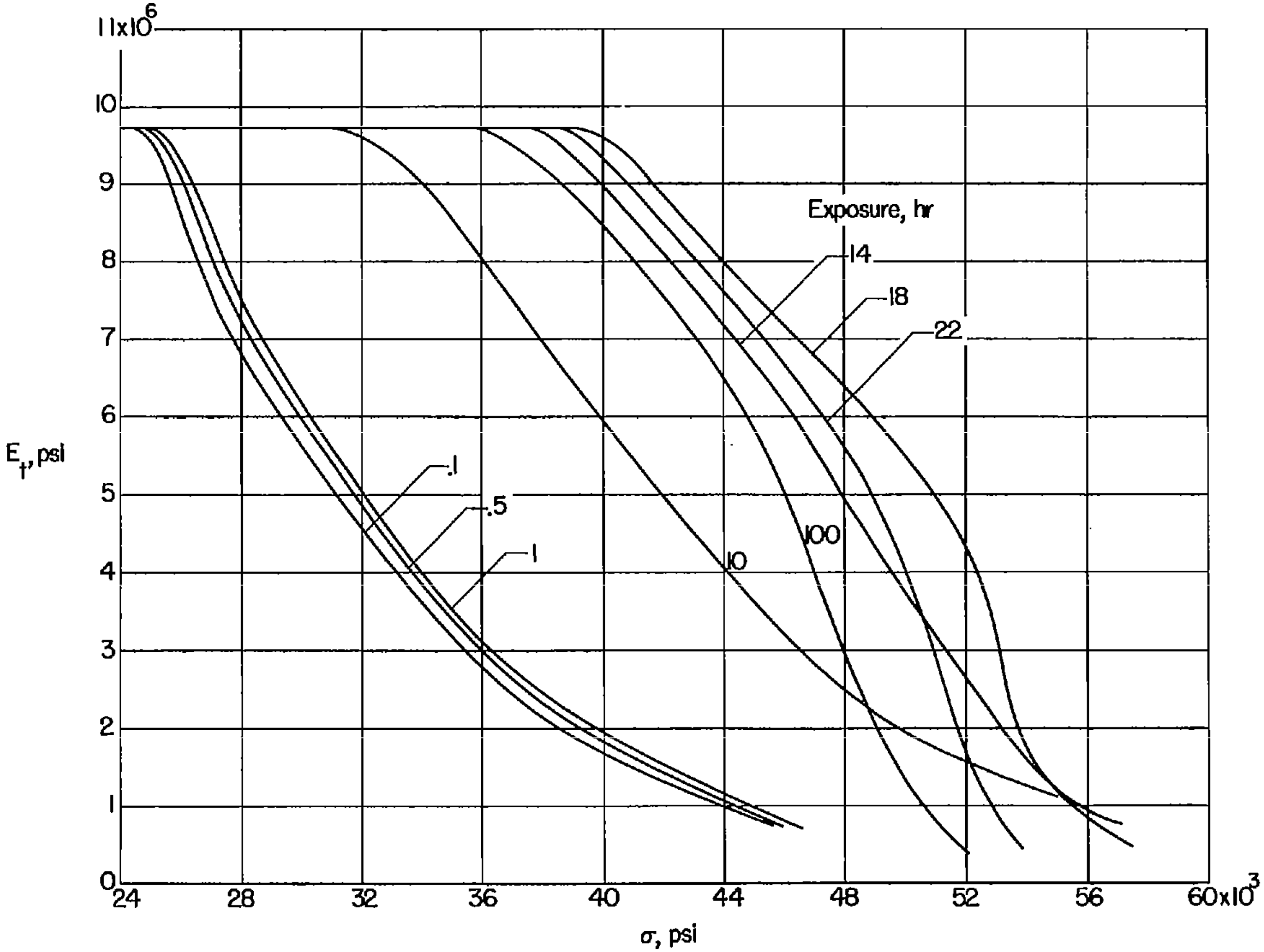


Figure 37.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 350° F.

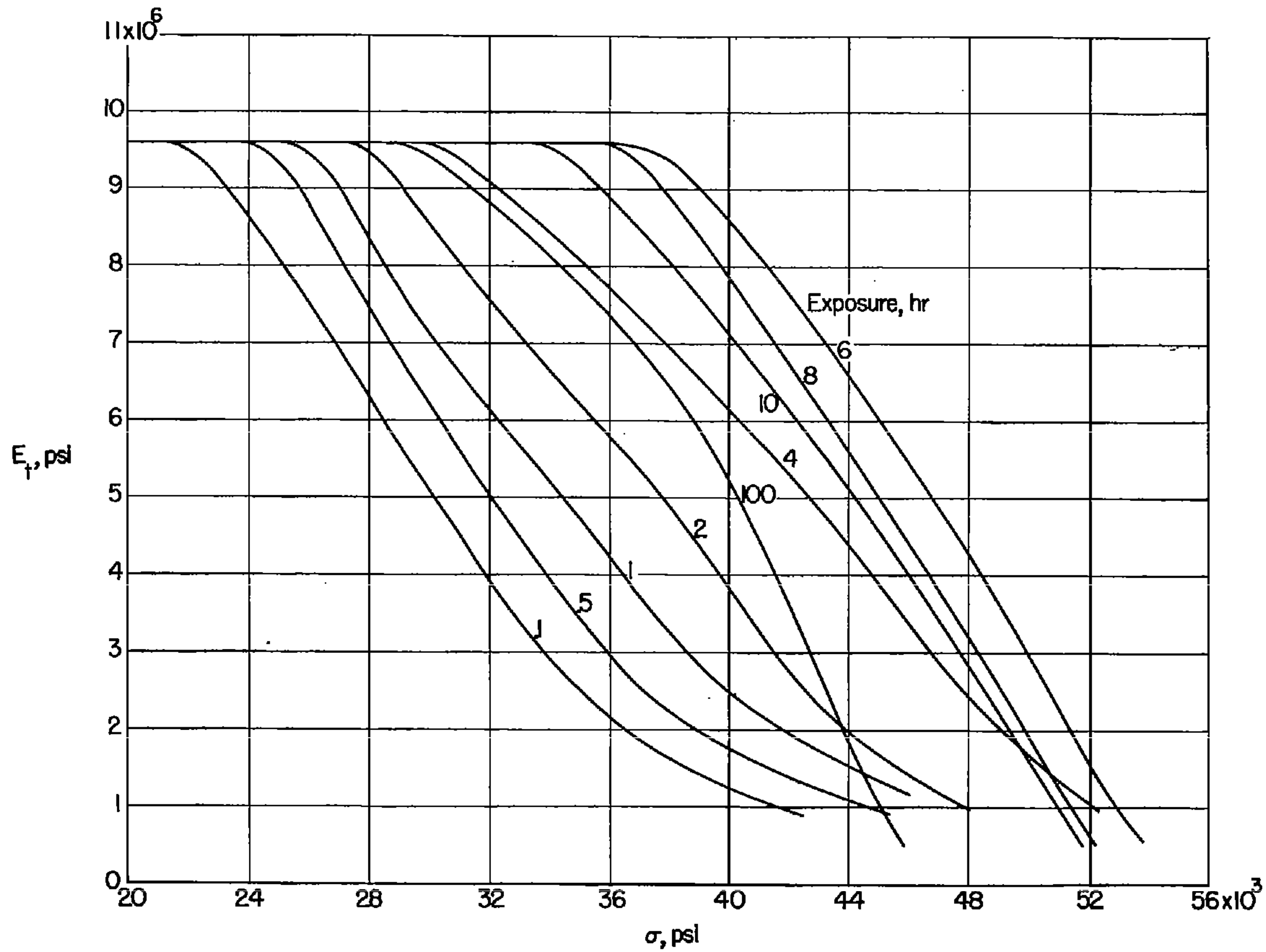


Figure 38.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 375° F.

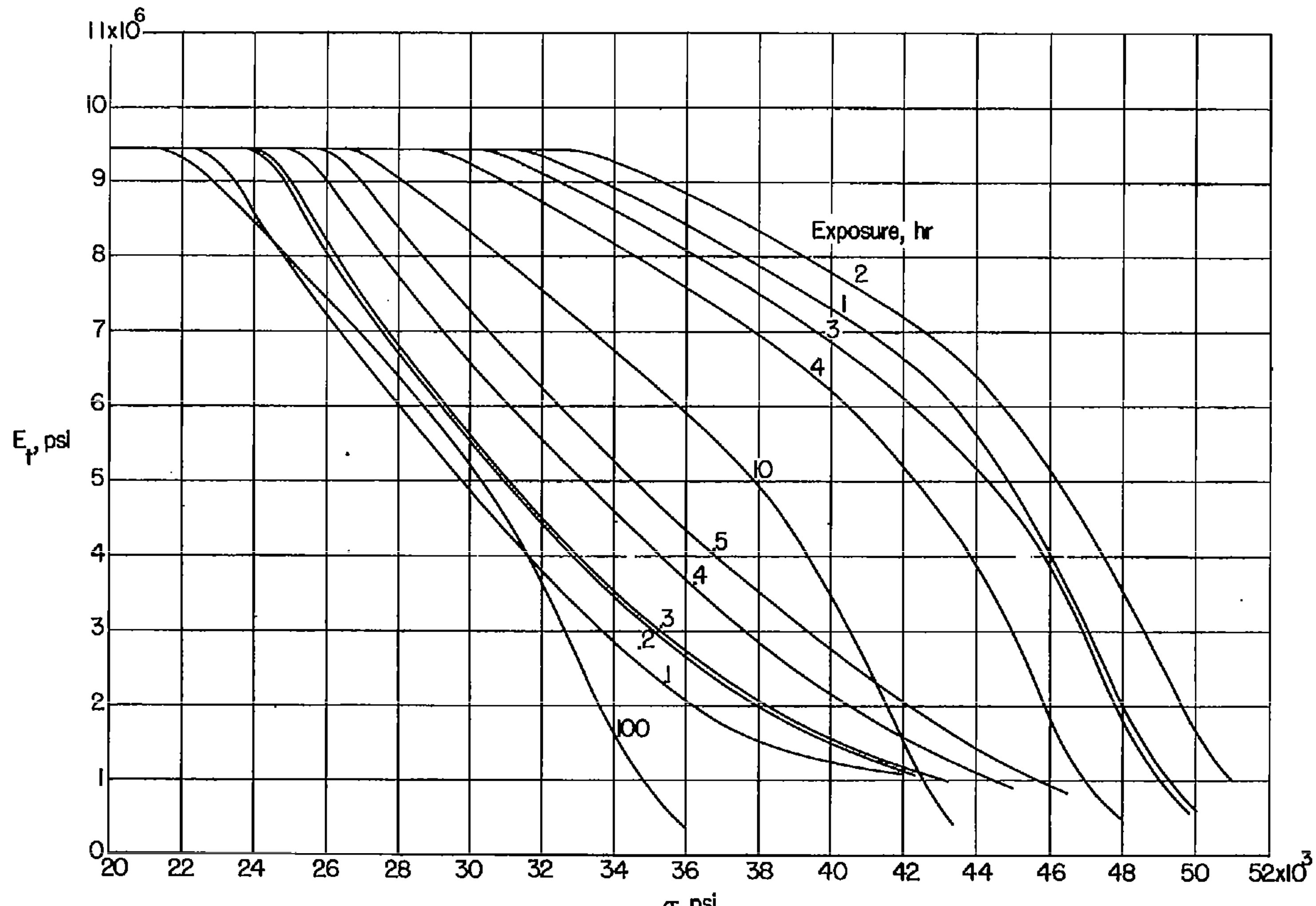


Figure 39.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 400° F.

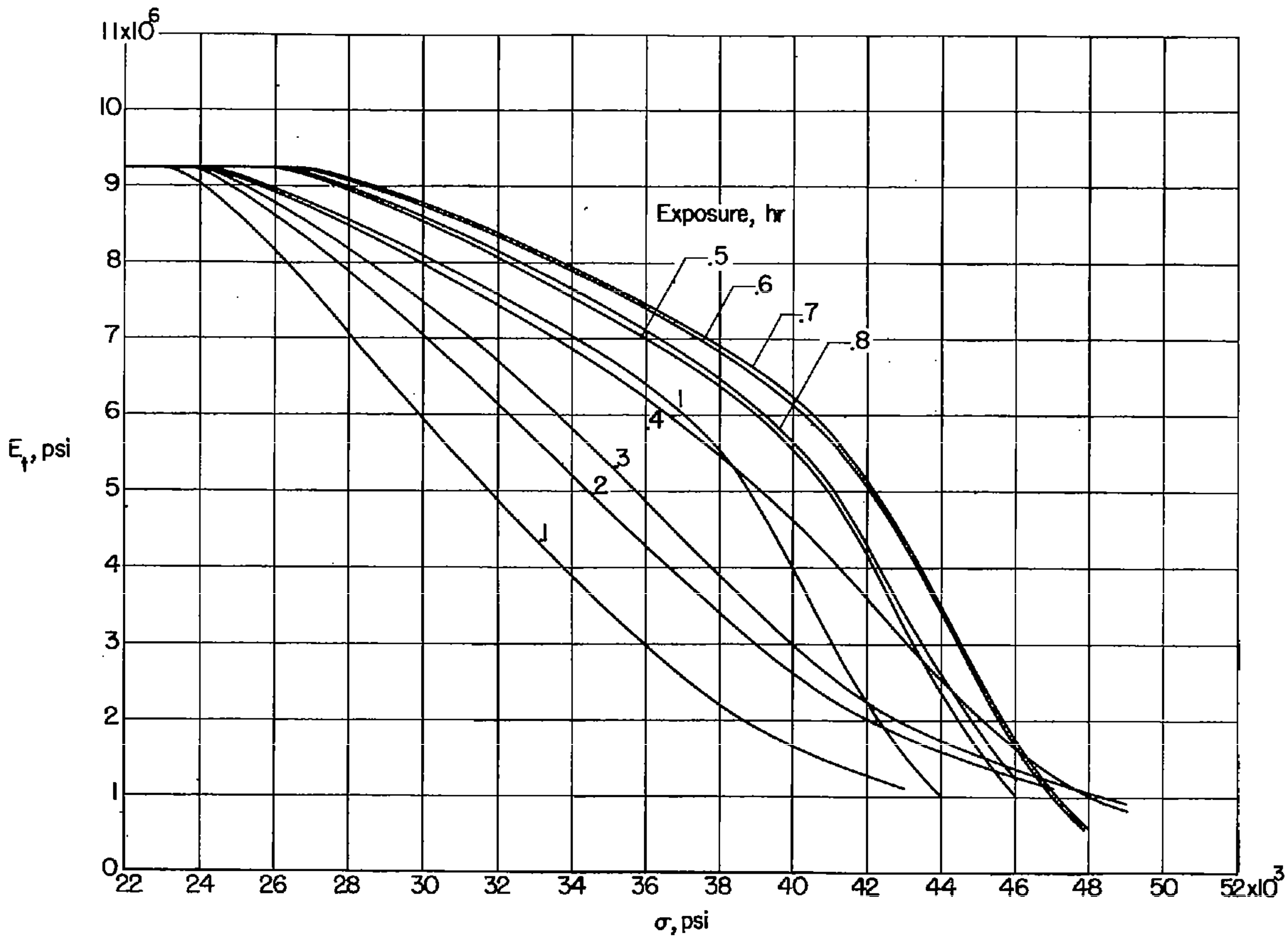


Figure 40.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 425° F.

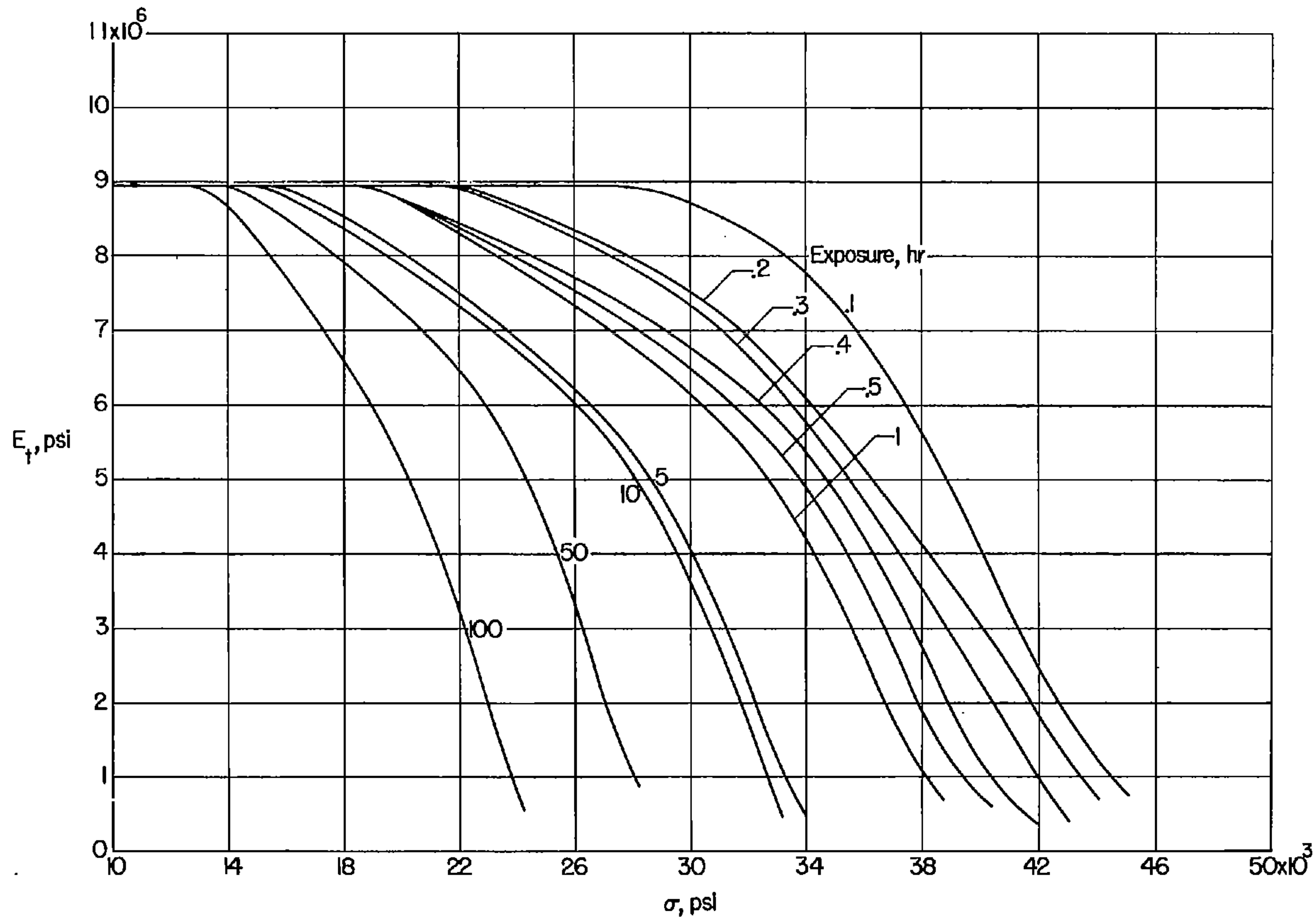


Figure 41.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 450° F.

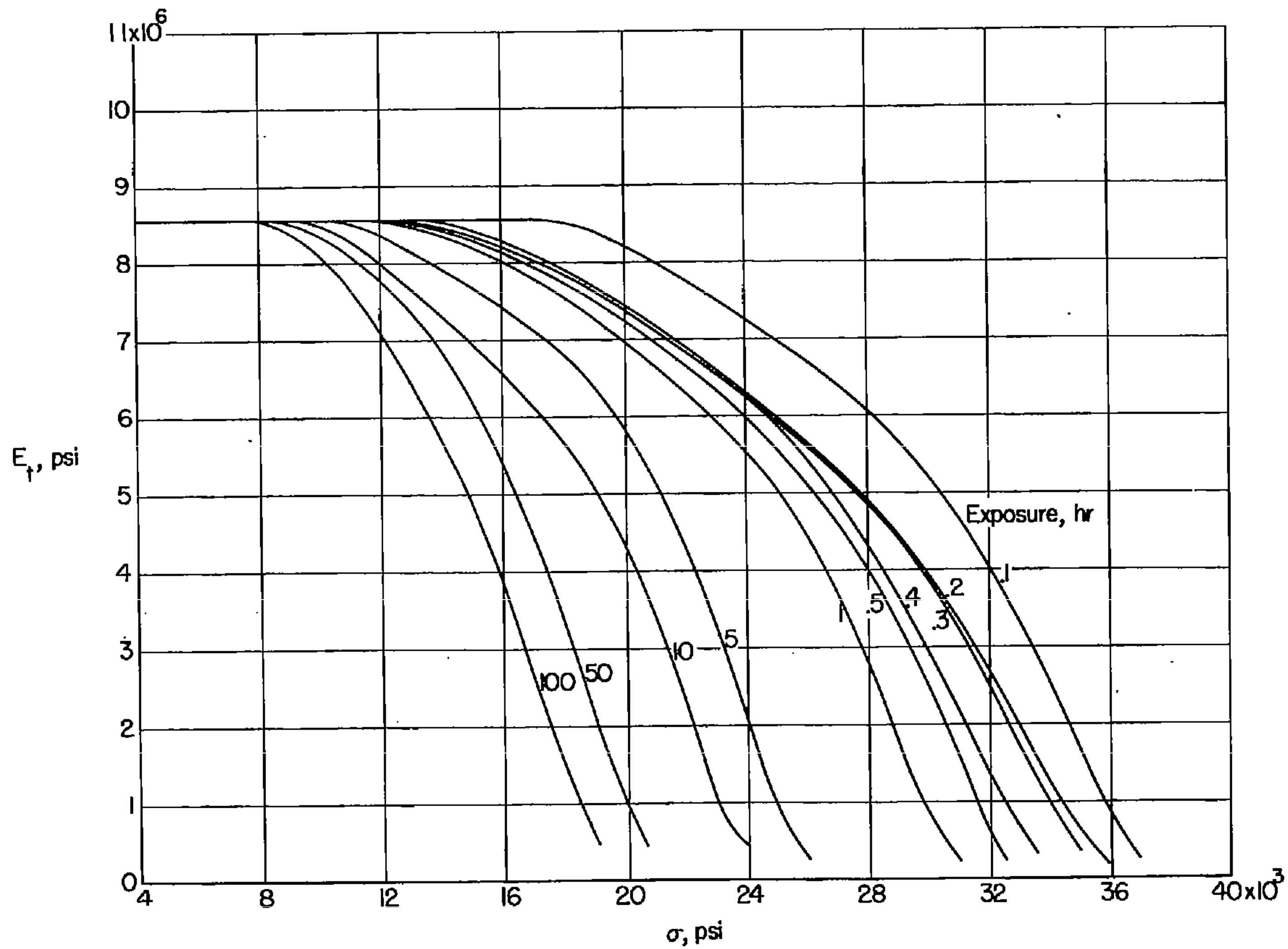


Figure 42.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 500° F.

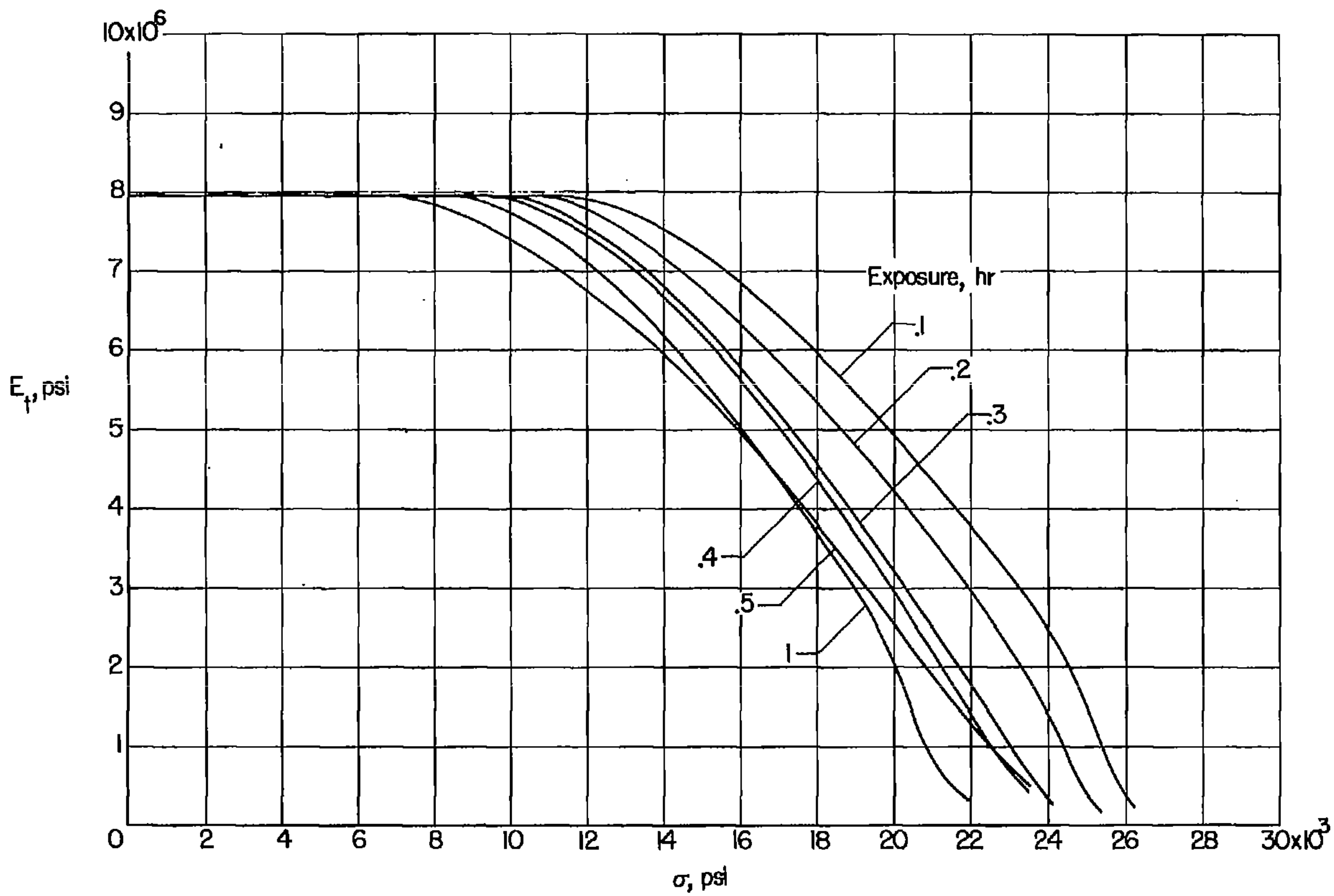


Figure 43.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 550° F.

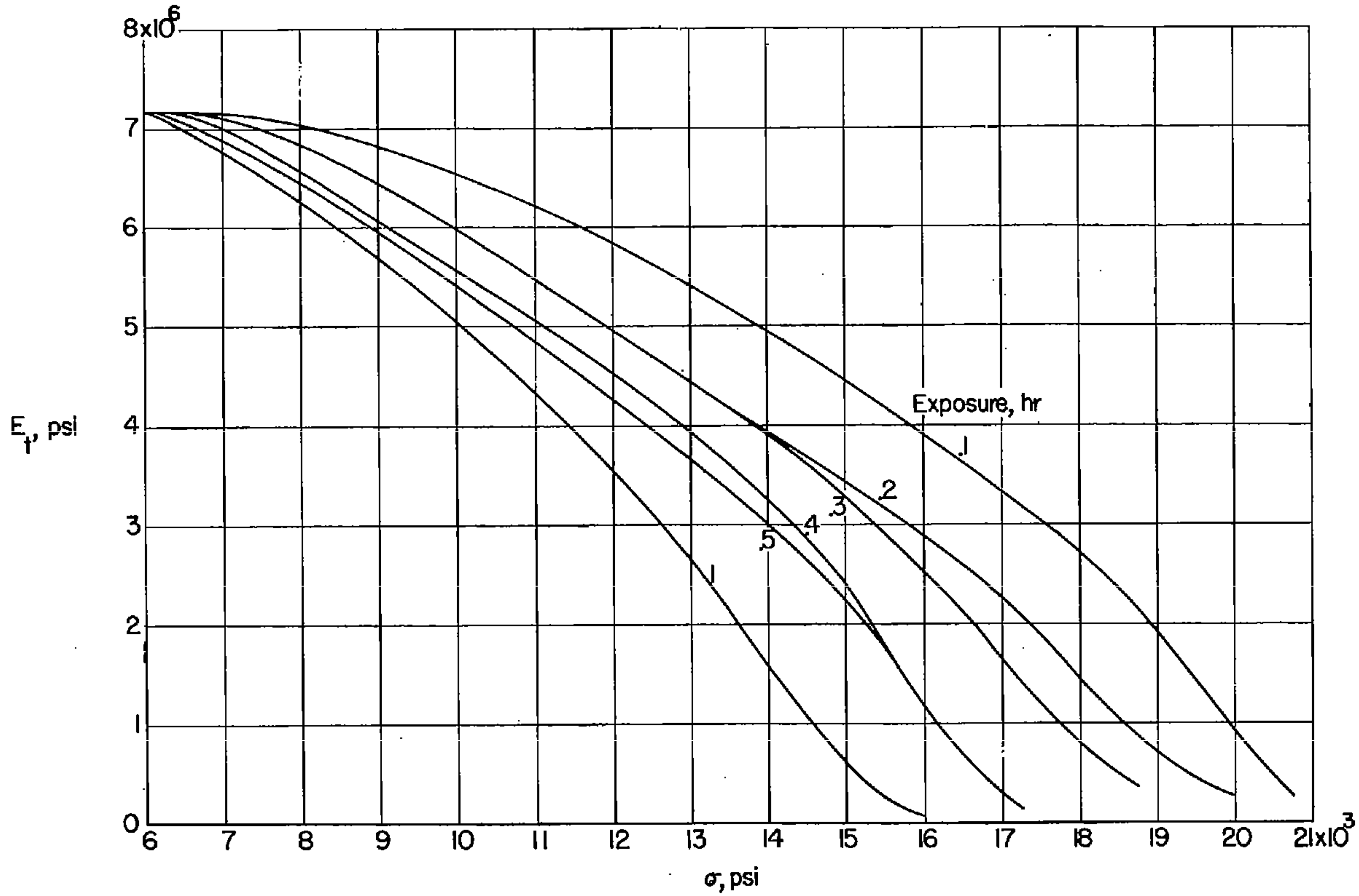


Figure 44.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 600° F.

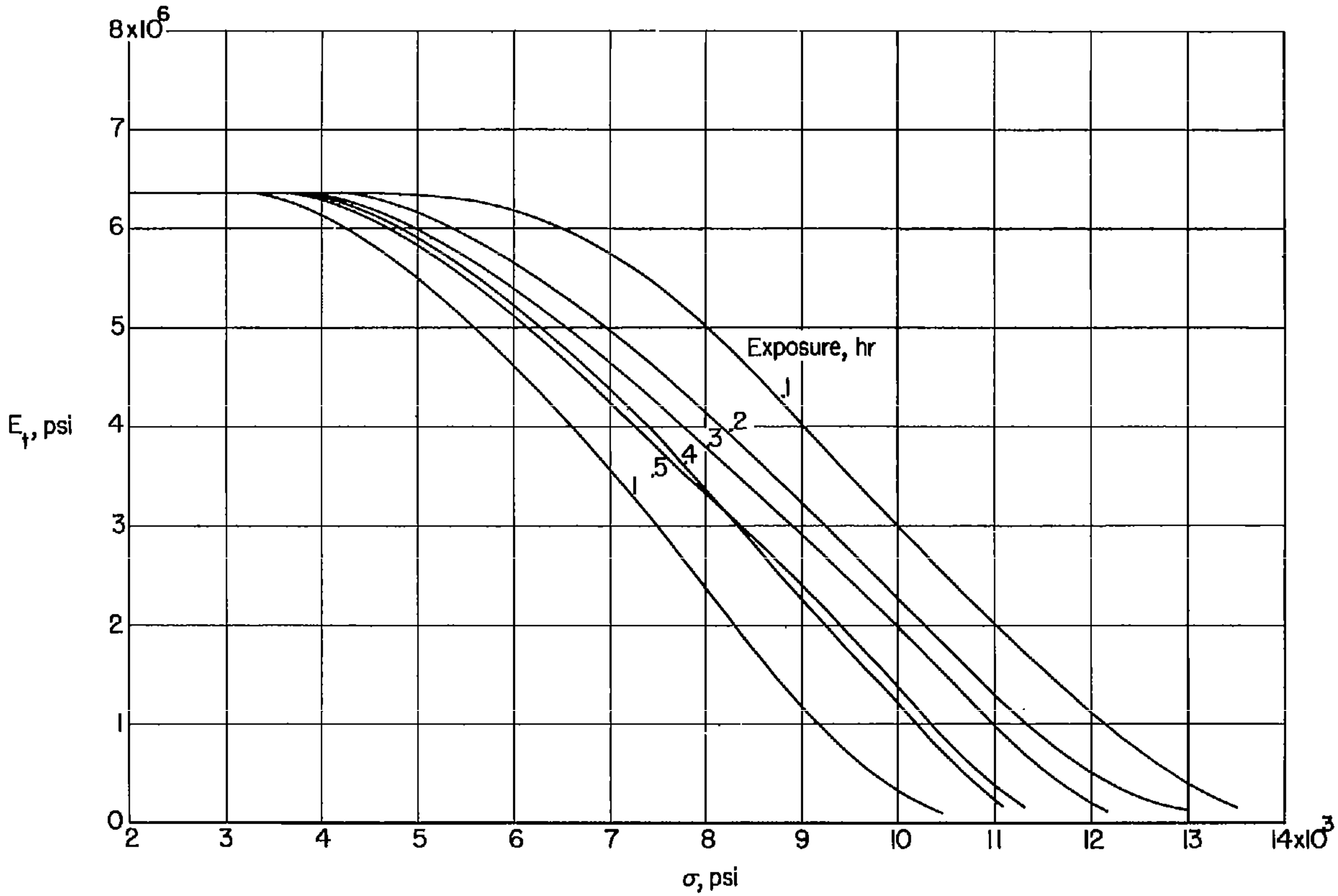


Figure 45.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 650° F.

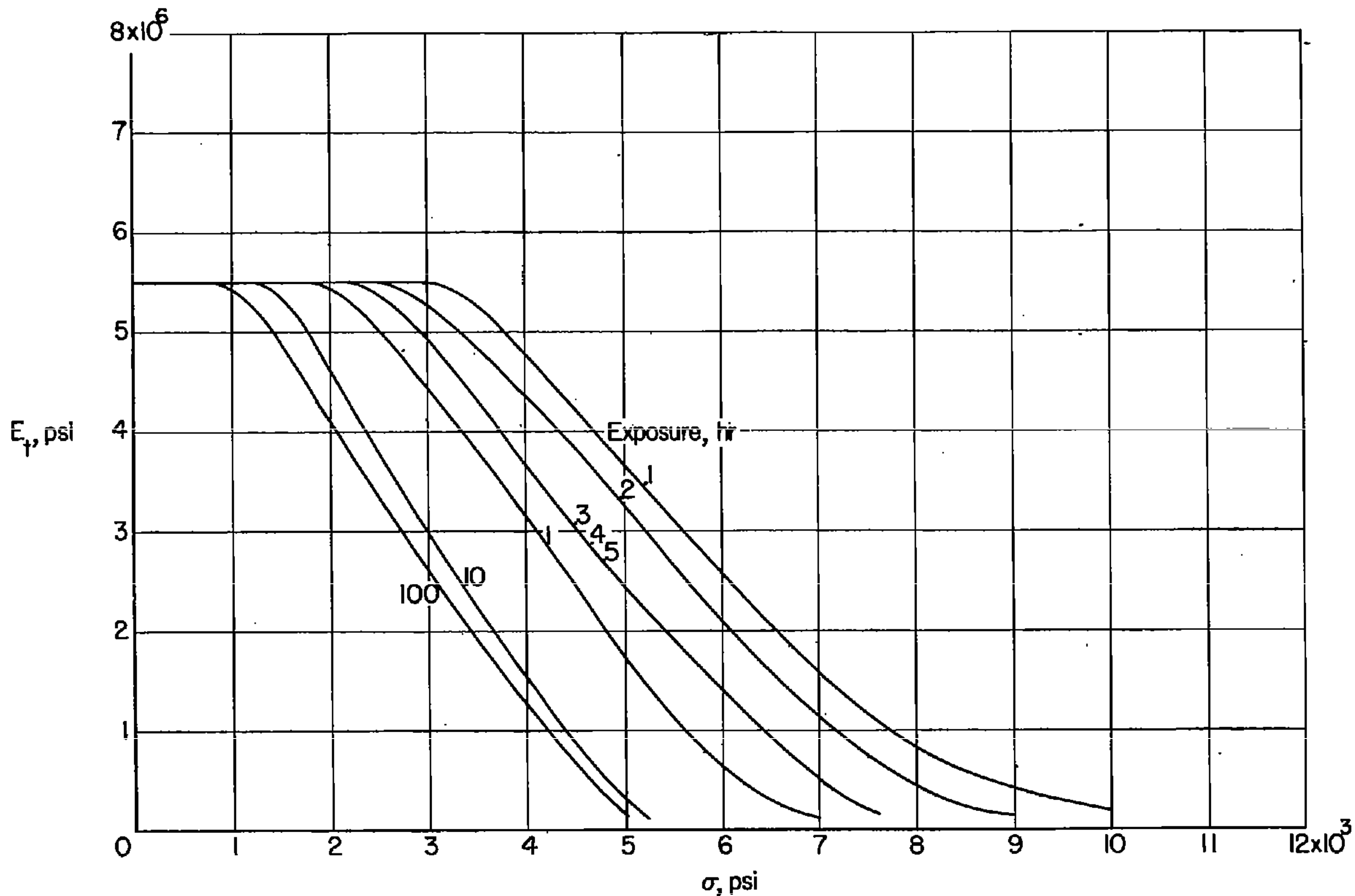
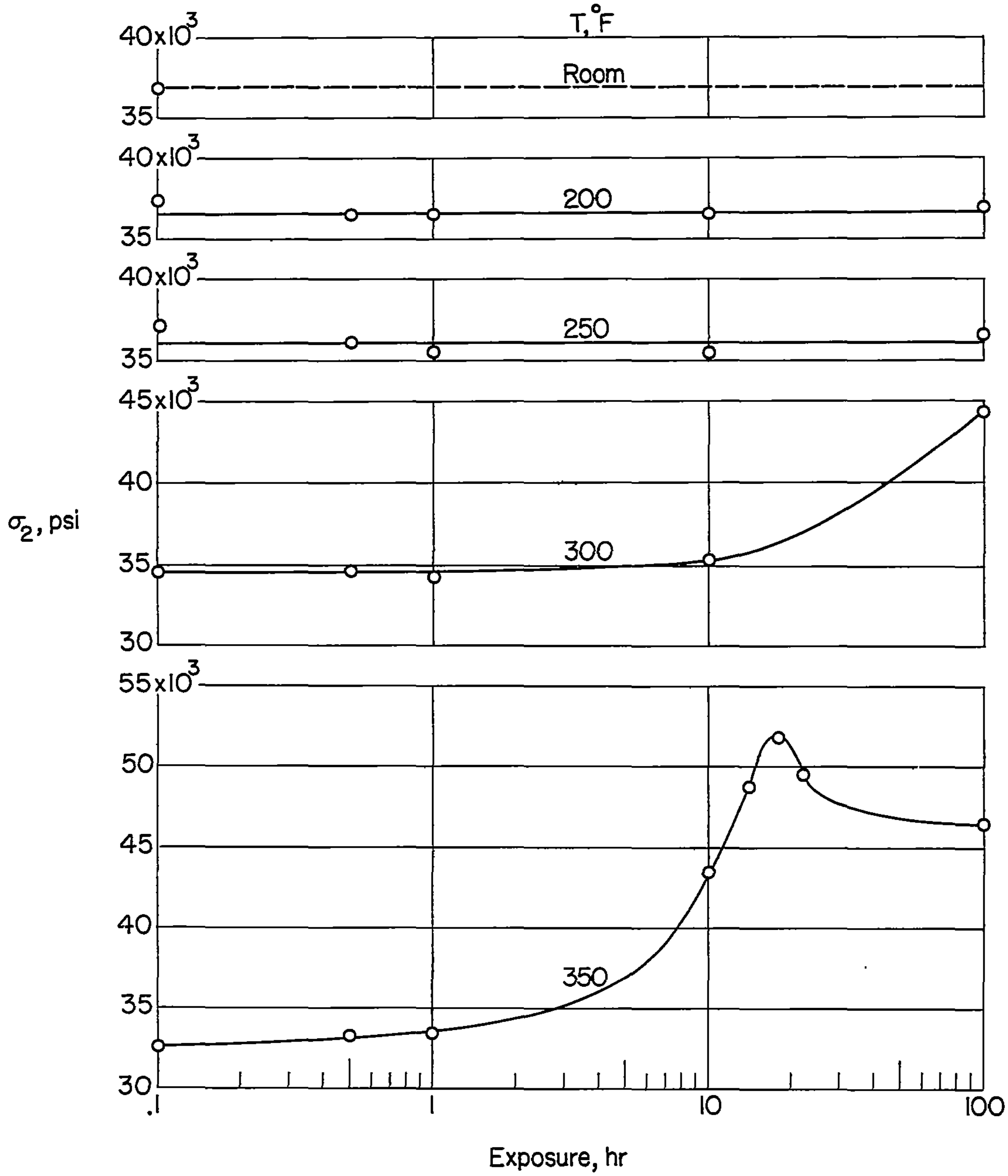
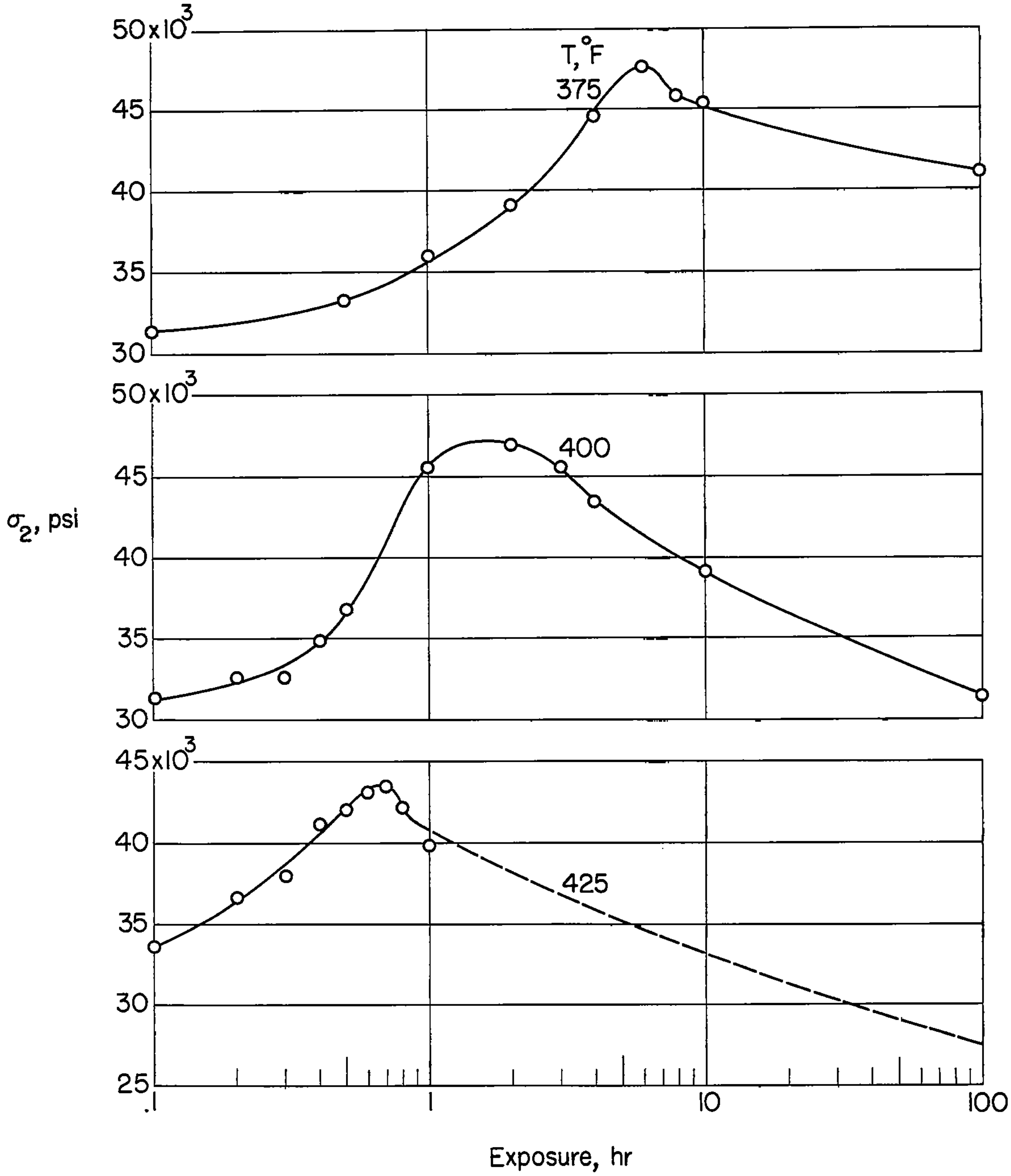


Figure 46.- Variation of tangent modulus with stress for 2024-T3 aluminum-alloy sheet at 700° F.



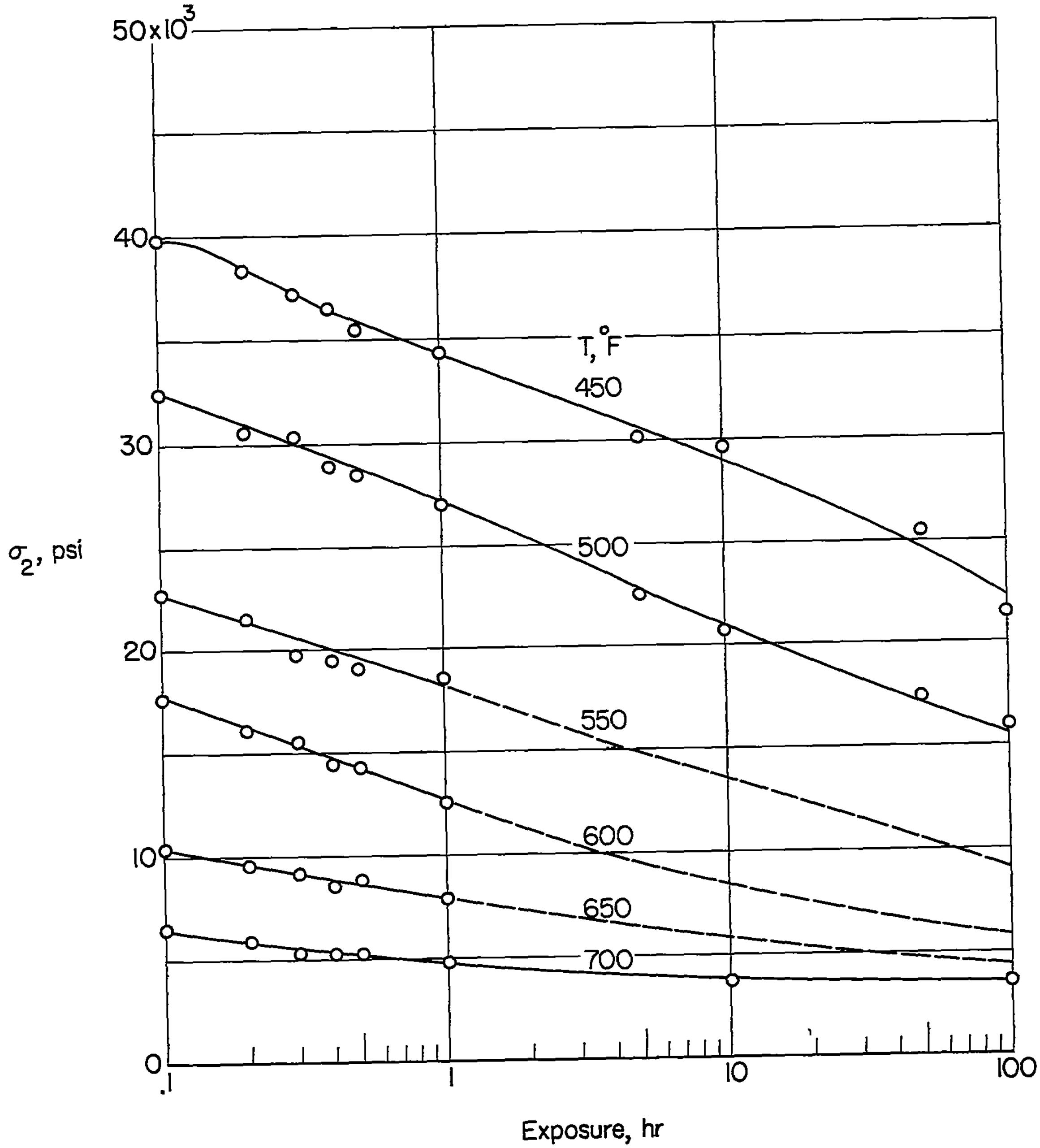
(a) Room temperature to 350° F.

Figure 47.- Effect of temperature and exposure time on σ_2 for 2024-T3 aluminum-alloy sheet. (Dashed portions of curves indicate estimated values obtained from cross plots of test data as in fig. 18.)



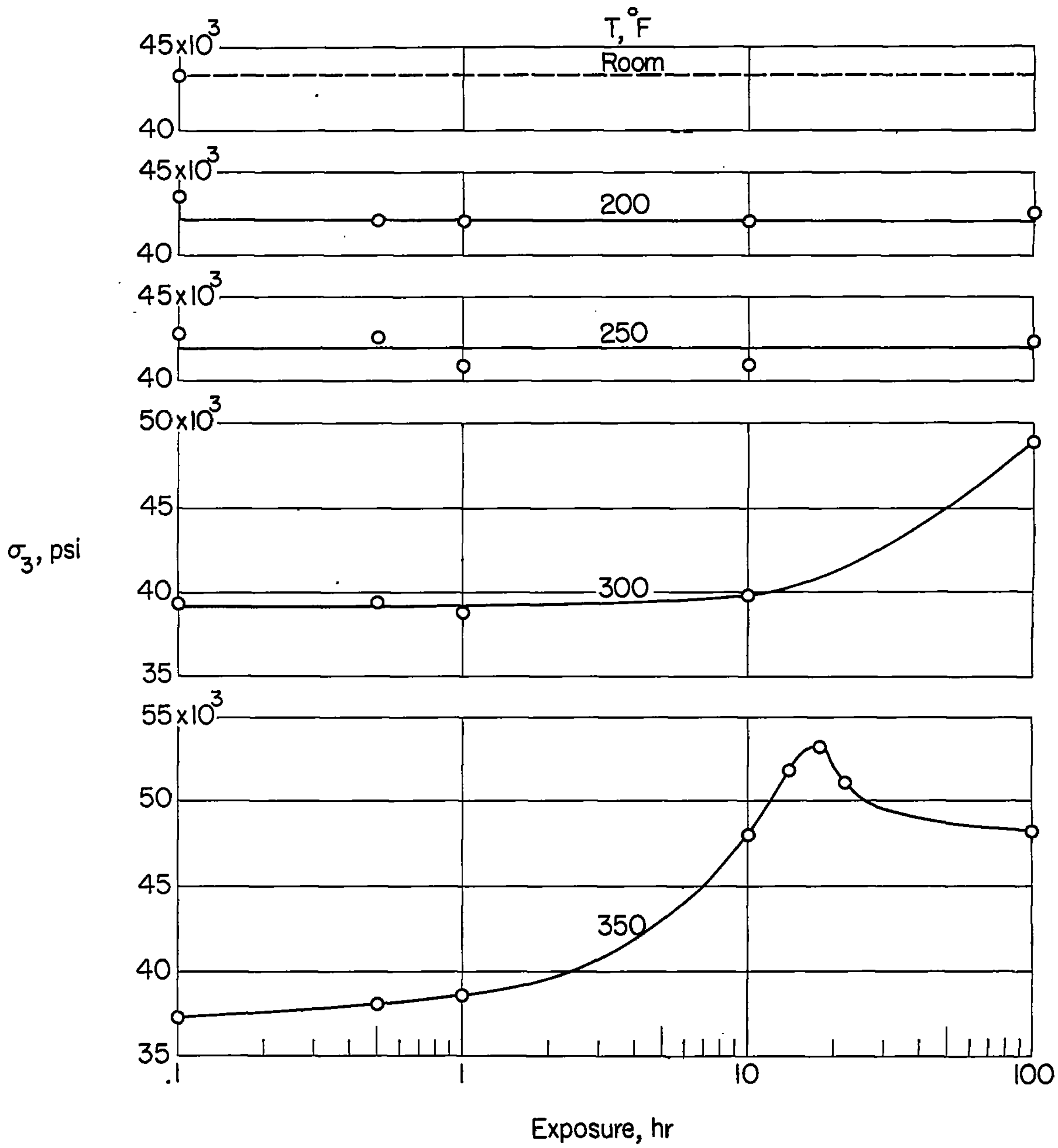
(b) 375° to 425° F.

Figure 47.- Continued.



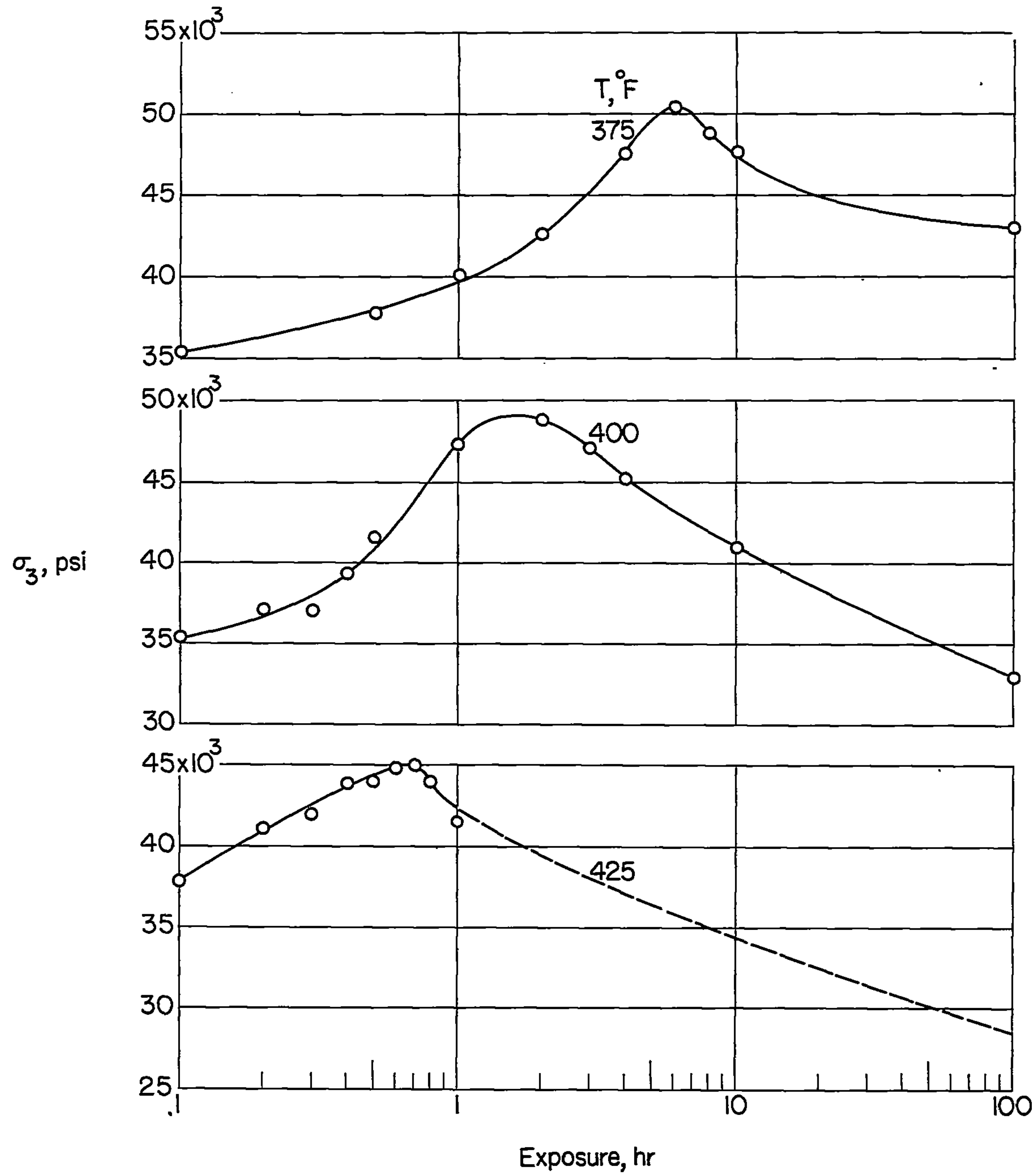
(c) 450° to 700° F.

Figure 47.- Concluded.



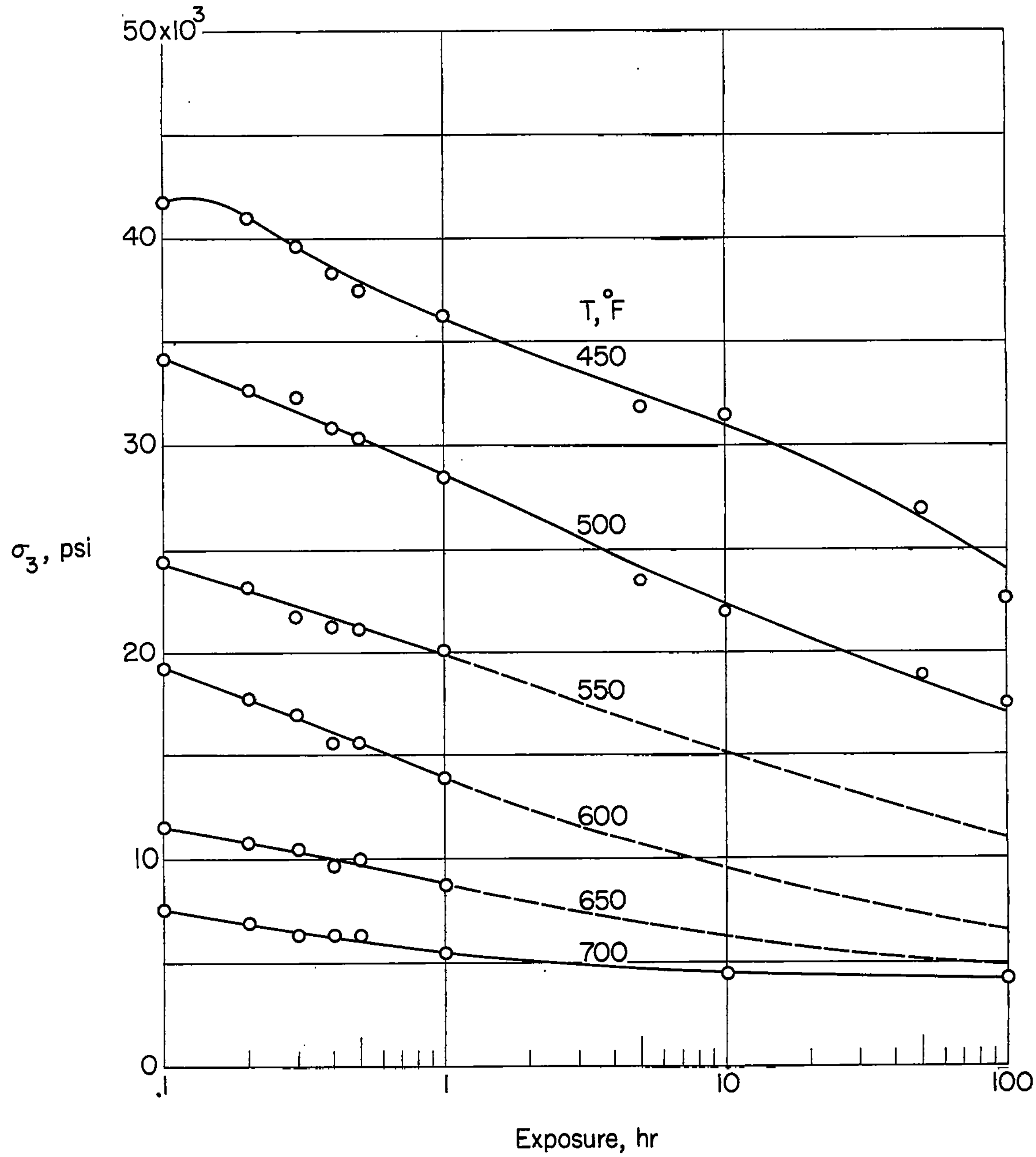
(a) Room temperature to 350° F.

Figure 48.- Effect of temperature and exposure time on σ_3 for 2024-T3 aluminum-alloy sheet. (Dashed portions of curves indicate estimated values obtained from cross plots of test data as in fig. 18.)



(b) 375° to 425° F.

Figure 48.- Continued.



(c) 450° to 700° F.

Figure 48.- Concluded.

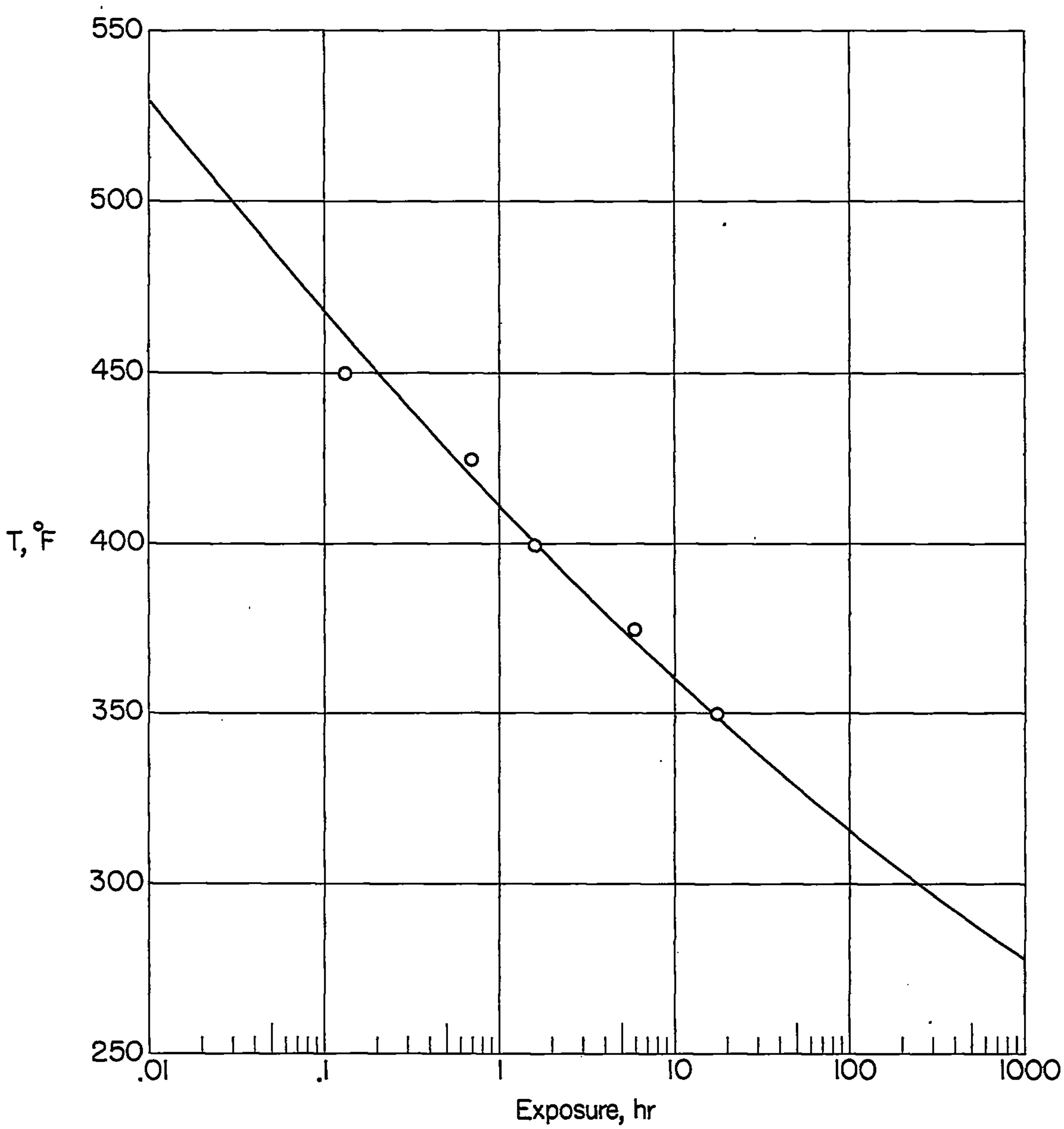


Figure 49.- Predicted combinations of temperatures and exposure times that produce maximum values of 0.2-percent-offset compressive yield stresses for 2024-T3 aluminum-alloy sheet. The symbols represent experimental results obtained from figure 17.

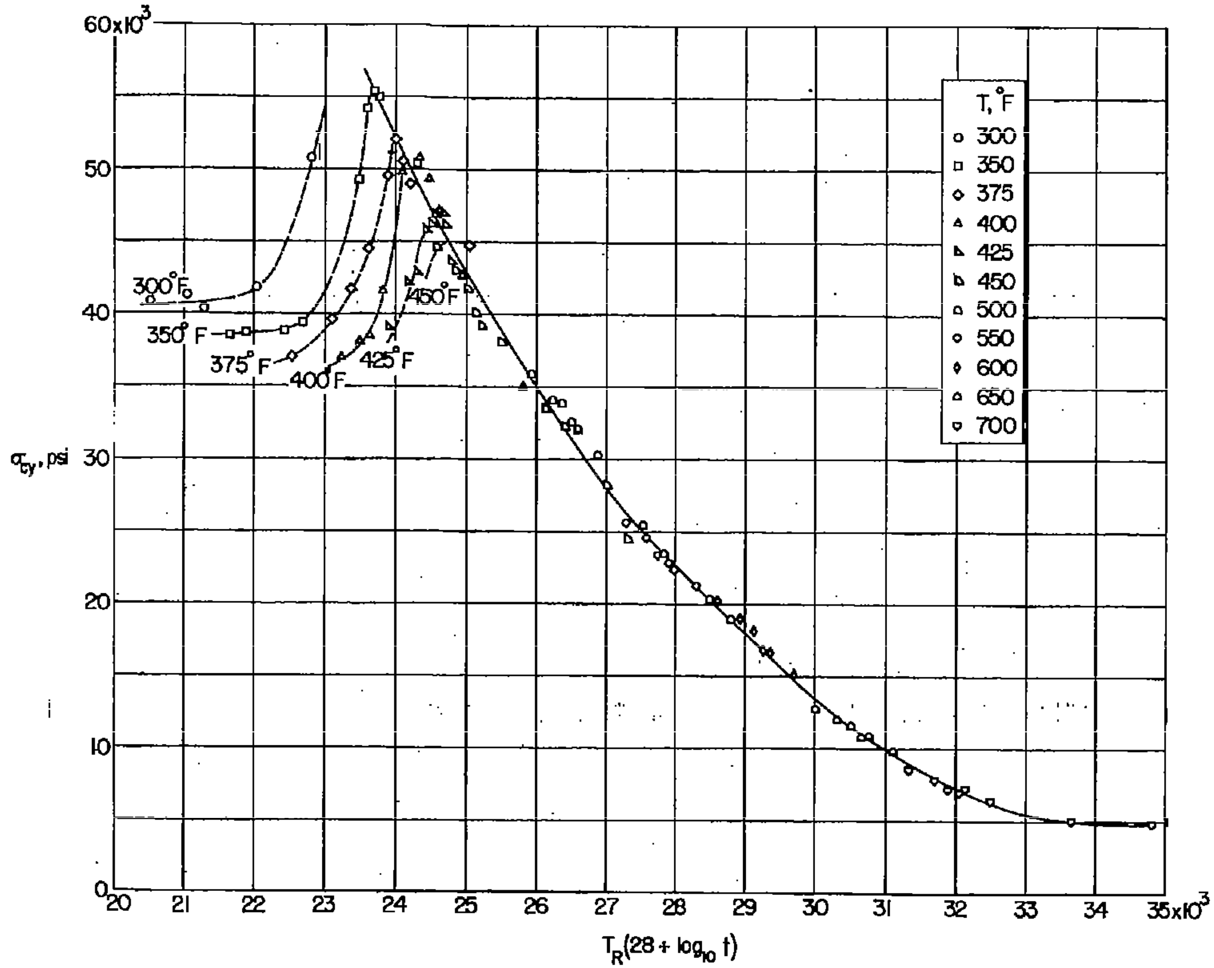


Figure 50.- Master curve of 0.2-percent-offset compressive yield stress for 2024-T3 aluminum-alloy sheet. (Dashed curves indicate time-temperature combinations which do not produce either maximum compressive yield stress or overaging of the material.)